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PREFACE

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Dr Kumardatt A Ganjre
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Issue: 1, Vol: 1

PAPER NUMBER - 01

**Impacts of AI on the Environment and
Sustainability**



Dr. Anjum Nazir Qureshi

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Impacts of AI on the Environment and Sustainability

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Abstract: AI is being extensively deployed across various sectors education, industrial operations, healthcare, agriculture, and telecommunications. AI-based tools have enabled faster analysis to support data-driven decisions. Researchers and conservationists harness the capabilities of AI to devise solutions for environmental conservation and sustainability. However, the larger energy consumption of some AI models and increased carbon footprint raise concerns about utilizing AI for various applications. With the increased discussions on topics like global warming and climate change, it is essential to have solutions to balance the negative environmental impacts.

Keywords: AI, sustainability, environment

1. Introduction

Artificial Intelligence (AI) has emerged as a transformation tool across various sectors. It has enabled paradigm shifts in working methods and made data-driven decisions. AI and Machine Learning (ML) have played a crucial role in facilitating the different processes that have evolved due to the surge in industrialization and technological advancements.

Some researchers have claimed that AI will revolutionize the fourth industrial revolution due to its speed and scope. Various sectors, such as education, healthcare, the public sector, and government organizations etc., are keenly interested in understanding the impact of AI and other emerging technologies on their businesses. Though

they feel that AI would bring numerous benefits to humanity, there may be some potential risks. Organizations adopting AI will benefit and give better results than those reluctant to use it. Deep learning (DL) is being considered as a popular tool for researchers in the coming years. AI will contribute to substantial improvements in many fields. Despite the benefits of AI, there are some controversial views and opinions on its impact on society [1]. Telecommunication is another industry looking forward to investing in AI to provide better services and earn better profits. ML, DL, generative AI, intelligent automation, and digital twins are some of the use cases in the telecom industry. Besides better services and profits, AI and its related algorithms will support better network performance, enhanced sales,

network operation centers, and customer experiences [2]. Similarly, AI has offered solutions in healthcare by improving the diagnosis process to enable better and faster treatment of diseases. AI is used to identify patterns by analyzing large datasets, thereby helping health professionals in personalized medicine. Moreover, the virtual healthcare assistant provides immediate solutions to health-related queries [3]. Additionally, industries are using AI for predictive maintenance to avoid disruptions in the production and supply chain due to the sudden breakdown of machines. AI-powered algorithms continuously monitor the machines for any malfunction and alert the maintenance team to initiate repairs. This helps prevent financial losses to the companies caused by production delays [4]. Personalized learning in education has become another popular application of AI. IT has enabled the learners to learn at their own pace. Moreover, customized courses to match the perception level of the students and immediate feedback have enhanced the teaching-learning process. The teachers use the feedback to improve their teaching methods and concentrate on student-centric scenarios, and learners use feedback to identify the areas in which they should work harder [5].

AI has numerous applications, especially when the concepts of smart cities, industrialization, urbanization, and globalization interest the researchers and the common people. At the same time, sustainability, climate change, circularity, and global warming are becoming equally important. Researchers, scientists, and industry owners are keen to ensure that these technologies are used to benefit the people and at the same time cause less or no harm to the environment. The objective of this paper is to study the impact of AI on the environment and sustainability.

2. Environmental and Sustainability

AI's capacity to analyze large datasets and facilitate real-time decision-making has helped satisfy the emphasis on environmental conservation. Some areas where AI is considered an enabler in helping the environment are precision agriculture, waste management, and disaster prevention.

ML techniques help farmers with better resource management by analyzing data to allow optimized water usage, better crop management, and controlled use of pesticides and fertilizers. This facilitates efficient agriculture practices and conserves soil and water [6]. Furthermore, it promotes environment-friendly pest control practices

through safer alternatives to the harmful chemicals. For instance, farmers can use biological agents like *Aspergillus Niger*, to manage the pest population. These solutions align with the conservation goals by reducing reliance on harmful chemicals to support environmental sustainability [7]. AI is usually integrated with IoT for smart urban management. It helps in route optimization for the waste collecting trucks, and helps to know the areas from which the waste has to be collected. IT reduces the time and energy needed for waste collection. Moreover, these facilities contribute to reducing waste, proper waste utilization, and pave the way for smarter waste management [8]. It helps optimize traffic flow to reduce congestion on roads and emissions. It facilitates controlling the lighting and temperature of the buildings by monitoring the environmental conditions [9]. Moreover, as the environmental conditions are continuously monitored, optimal usage of renewable energy sources is ensured to avoid disruptions in power supply caused by their intermittent nature. All these provisions help in having energy-efficient and green buildings in smart cities. AI in smart cities promotes environmental conservation. Using renewable energy to fulfill the power requirements of smart buildings and industrial purposes reduces

greenhouse gas emissions and minimizes the environmental impacts caused by conventional energy sources.

AI's versatility is being used efficiently for disaster prevention and maintaining biodiversity. ML techniques and aerial imagery help detect post-disaster environmental damage. The rapid identification of habitat destruction and pollution levels helps in the timely implementation of conservation efforts [10]. ML can enhance biodiversity conservation by predicting the species facing risks of extinction. This allows for execution measures to save the endangered species. AI-driven insights help conservationists implement environmental conservation and preserve biodiversity by continuously monitoring and managing the protected areas [11].

AI supports sustainability in the energy sector by harnessing ML for energy storage, its harvesting, and management. This promotes sustainable energy practices that are pivotal to addressing climate change challenges [12]. Education is another sector that can efficiently use AI to attain sustainability. Equitable access to AI driving tools is essential to foster a sustainable educational

environment. This initiative will promote social equity [13].

3. Environmental Challenges of AI

Although AI has transformed various sectors and supported environmental conservation, some challenges should be addressed to ensure sustainability. One of the significant concerns of using AI technologies is their higher energy consumption and carbon footprint. Most AI systems utilize considerable computational resources. This increases the energy consumption and hence the greenhouse gas emissions. The energy consumption of AI applications, especially while analyzing large datasets, and the consumption demands of the data processing centers raise concerns over their sustainability. Moreover, though the transition to renewable energy and its integration with AI is considered an energy-efficient approach, the resource allocations and infrastructure should be managed cautiously to balance the energy use.

The sustainability of the infrastructure used with these technologies should be assessed cautiously to ensure their alignment with the sustainability goals. Additionally, though AI ensures better resource management, it exacerbates the risks of ethical considerations and equity. It requires reframing the

regulations and policies to ensure that AI systems are designed by prioritizing ethical considerations and balancing the environmental impacts. This calls for a comprehensive approach to AI to integrate environmental responsibility into the ethical frameworks. For the integration of AI into sustainable frameworks, it is essential to understand the interconnectedness of the Sustainable Development Goals (SDGs). Preventing negative impacts among SDGs, like energy consumption and responsible production, is another challenge for using AI applications. Moreover, ensuring equitable access to AI technologies is challenging amid the digital divide and for countries that lack the infrastructure to use them. There is a lack of professionals to train and change the mindset of those reluctant to adapt to AI. All these factors hinder the development of inclusive and accessible AI solutions to promote sustainability and ensure that people benefit from these advancements. The negative impacts of AI on the environment will inhibit achieving goals like good health (SDG 3) and poverty alleviation (SDG 01). Though some of the AI applications will support SDGs like clean water (SDG 06), climate action (SDG 13), sustainable cities (SDG 11), and responsible production and consumption (SDG 12), the negative impacts

on the environment will diminish the efforts to achieve other goals.

4. Conclusion

This paper has studied the impact of AI on the environment and achieving sustainability. AI supports sectors like agriculture, urban management, and waste management, and indirectly conserves soil and water. However, the large energy consumption of the AI models and their carbon footprint overshadows the positive impact of AI on the environment. The future research in this field should focus on socio-economic implications, environmental costs, development of robust regulatory frameworks and enhancing partnerships to enable AI-driven sustainability initiatives.

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PAPER NUMBER - 02

**Blockchain Technologies for Secure and
Transparent Artificial Intelligence Systems**



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Blockchain Technologies for Secure and Transparent Artificial Intelligence Systems

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Abstract—The rapid development and vast deployment of synthetic intelligence (AI) systems have raised great concerns concerning security, transparency, and trustworthiness. This paper explores the integration of blockchain technology as a potential way to deal with these demanding situations in AI systems. We examine the current vulnerabilities in AI architectures and advocate a blockchain-primarily based framework that complements facts integrity, model responsibility, and audit trails during the AI lifecycle. Our research demonstrates that disbursed ledger technologies can provide immutable records of education facts provenance, model development approaches, and inference selections, thereby increasing trust and verification talents. We examine several implementation methods, together with permissioned and permissionless blockchain architectures, smart contract integration for automatic governance, and consensus mechanisms optimized for AI workflows. Performance opinions imply that at the same time as blockchain integration introduces computational overhead, the safety and transparency advantages outweigh those prices in essential programs. We conclude that blockchain-secured AI represents a promising paradigm for growing more strong, accountable, and shrewd trustworthy structures, especially in domains where selection verification and auditability are paramount.

Index Terms—Blockchain, artificial intelligence, protection, transparency, dispensed ledger generation, smart contracts, version governance, statistics provenance.

INTRODUCTION

Artificial Intelligence (AI) technology has demonstrated tremendous abilities throughout several domain names, from pc vision to natural language processing. However, as AI systems become increasingly included into crucial infrastructure and choice-making strategies, worries regarding their security, transparency, and trustworthiness have grown proportionally [1]. Traditional AI architectures face numerous great challenges: vulnerability to hostile assaults, opacity in choice-making techniques, difficulties in verifying education records provenance, and constrained duty for computerized selections [2]. Blockchain technology, with its essential residences of decentralization, immutability, and transparency, affords a promising solution to these demanding situations [3]. Originally advanced as the underlying technology for cryptocurrencies, blockchain has developed into a flexible distributed ledger applicable to numerous domains past finance. Its ability to create tamper-resistant information, set up consensus among disbursed parties, and automate believe thru smart contracts makes it specifically appropriate for

addressing the security and transparency requirements of AI structures [4].

This paper explores the intersection of blockchain and AI technology, offering a framework for blockchain-secured artificial intelligence that complements protection, transparency, and believe all through the AI lifecycle. We observe how blockchain can be employed to:

1. Establish verifiable provenance for training information
2. Create immutable audit trails of model development and updates
3. Record inference selections with cryptographic verification
4. Implement decentralized governance mechanisms for AI structures

We evaluate numerous implementation approaches the use of specific blockchain arch

B. Blockchain Technology Fundamentals

Blockchain technology provides a distributed ledger structure where data is organized into blocks, cryptographically linked in a chain, and synchronized across multiple nodes in a network [5]. Key properties include:

1. **Immutability:** Once recorded, data cannot be altered without consensus, creating tamper-evident records.
2. **Decentralization:** The ledger is distributed across multiple parties, eliminating single points of failure.
3. **Transparency:** Transactions are visible to all authorized participants.
4. **Consensus Mechanisms:** Various algorithms (Proof of Work, Proof of Stake, Practical Byzantine Fault Tolerance) ensure agreement on the ledger state.
5. **Smart Contracts:** Self-executing code that automatically enforces agreements when predetermined conditions are met.

Blockchain architectures are broadly categorized as permissionless (public) or permissioned (private/consortium) [6]. Permissionless blockchains allow anyone to participate, while permissioned blockchains restrict participation to approved entities, offering different

trade-offs between decentralization, performance, and privacy.

C. Existing Work on Blockchain-AI Integration

Several researchers have begun exploring the combination of blockchain and AI. Salah et al. [7] proposed using blockchain to create verifiable AI marketplaces, while Dinh and Thai [8] examined how smart contracts ought to automate governance in AI systems. Chen et al. [9] proven a blockchain-primarily based approach for federated learning that preserves privateness whilst enabling model verification.

Commercial tasks have also emerged, together with Ocean Protocol's facts marketplace for AI and Fetch. Ai's decentralized AI network [10]. However, most current paintings have centered on specific elements of the AI lifecycle rather than providing comprehensive frameworks that address protection and transparency at some stage in the complete system.

III. BLOCKCHAIN-SECURED AI FRAMEWORK

We endorse a comprehensive framework for integrating blockchain technology with AI structures to enhance protection, transparency, and trust during the AI lifecycle. The framework addresses four key phases: data acquisition and provenance, version improvement and training, inference and decision-making, and governance and compliance.

A. Data Acquisition and Provenance

The first-class and provenance of training information extensively affects AI gadget overall performance and trustworthiness. Our framework employs blockchain to:

1. Record Data Sources: Create immutable statistics of records origins, including supply identifiers, timestamps, and cryptographic hashes of uncooked facts.
2. Track Data Transformations: Document preprocessing steps, augmentation strategies, and characteristic engineering strategies.
3. Verify Consent and Usage Rights: Store cryptographic proofs of statistics utilization permissions and consent agreements.
4. Enable Audit Trails: Provide comprehensive visibility into facts lineage for regulatory compliance and bias detection.

B. Model Development and Training

The model development phase benefits from blockchain integration through:

1. **Version Control:** Immutable record of model architecture, hyperparameters, and training configurations.

1. Training Process Verification: Logging of education metrics, intermediate checkpoints, and validation consequences.

2. Collaborative Development: Secure mechanism for a couple of parties to make contributions to model improvement with attribution.

3. Reproducibility Guarantees: Complete traceability of the development process permitting independent verification. We enforce this the use of a clever version registry agreement that records version metadata, schooling configurations, and cryptographic hashes of model weights at numerous checkpoints.

C. Inference and Decision-Making

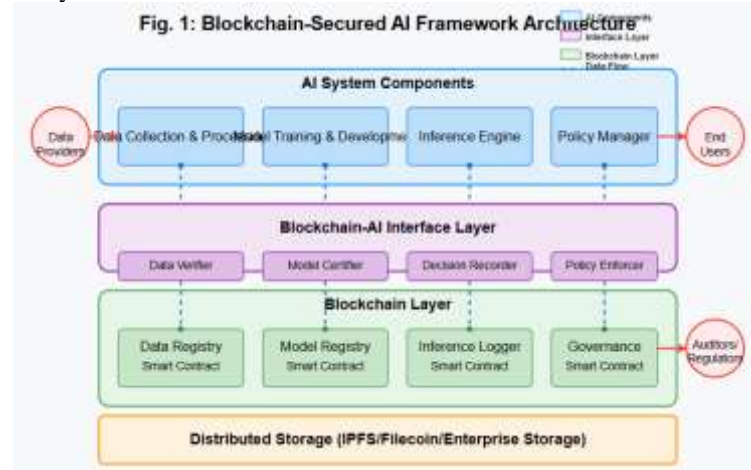
During operational deployment, blockchain ensures duty through:

1. Recording Inference Inputs: Creating tamper-obvious logs of inputs supplied to AI structures.
2. Documenting Decision Outputs: Storing version outputs and self-belief ratings in immutable records.
3. Establishing Decision Responsibility: Maintaining clear chains of duty for automated decisions.
4. Enabling Verification: Allowing impartial parties to verify that specific inputs produced unique outputs. Implementation uses an inference logging contract that data transaction hashes representing inference activities, with elective off-chain storage for privacy-sensitive facts.

D. Governance and Compliance

Blockchain helps advanced governance of AI systems via:

1. Automated Policy Enforcement: Smart contracts that encode and put in force utilization policies and ethical tips.
2. Access Control: Cryptographic mechanisms to make sure handiest legal events can regulate or install fashions.
3. Regulatory Compliance: Automated reporting and immutable audit trails for regulatory necessities.
4. Decentralized Governance: Multi-stakeholder governance models enforced through blockchain consensus. Fig. 1 illustrates the complete framework architecture, showing the relationship between blockchain components and traditional AI system elements.



IV. IMPLEMENTATION APPROACHES

We evaluate several implementation approaches for blockchain-secured AI systems, considering the trade-offs between security, performance, scalability, and privacy requirements.

A. Blockchain Architecture Selection

The choice of blockchain architecture significantly impacts the security and performance characteristics of the system:

1. **Permissionless Blockchains** (e.g., Ethereum, Polka dot):
 - Advantages: Maximum decentralization, public verifiability, resistance to censorship
 - Disadvantages: Lower throughput, higher latency, limited privacy, higher operational costs
2. **Permissioned Blockchains** (e.g., Hyperledger Fabric, Quorum):
 - Advantages: Higher throughput, decreased latency, configurable privacy, managed get entry to
 - Disadvantages: More centralized, capacity for collusion among validators
 - Our experiments imply that permissioned blockchains are typically greater suitable for corporation AI programs with specific overall performance requirements and privacy concerns, whilst permissionless blockchains offer more potent ensures for public-dealing with AI systems in which maximum transparency and censorship resistance are priorities.

B. On-Chain vs. Off-Chain Storage

AI systems typically involve large datasets and models that exceed practical blockchain storage capacities. We propose a hybrid approach:

1. **On-Chain Components:**
 - Metadata about data sources, models, and inferences
 - Cryptographic hashes of datasets and model weights
 - Access control policies and governance rules
 - Smart contracts for automated verification
2. **Off-Chain Components:**
 - Raw training data
 - Model weights and parameters
 - Computation-intensive operations
 - Privacy-sensitive information

This hybrid approach leverages content-addressable storage systems like IPFS, File coin, or enterprise storage solutions, with blockchain maintaining cryptographic links to ensure data integrity.

Consensus Mechanisms

For AI-particular blockchain implementations, consensus mechanism choice ought to consider the necessities of AI workflows:

1. Proof of Authority (PoA): Suitable for consortium models where regarded entities collaborate on AI improvement. PoA is suited for both private networks and public networks, like POA Network or Eurus, where trust is distributed
2. Practical Byzantine Fault Tolerance (PBFT): Provides high throughput for permissioned networks
3. Delegated Proof of Stake (DPoS): Balances decentralization with overall performance for public networks

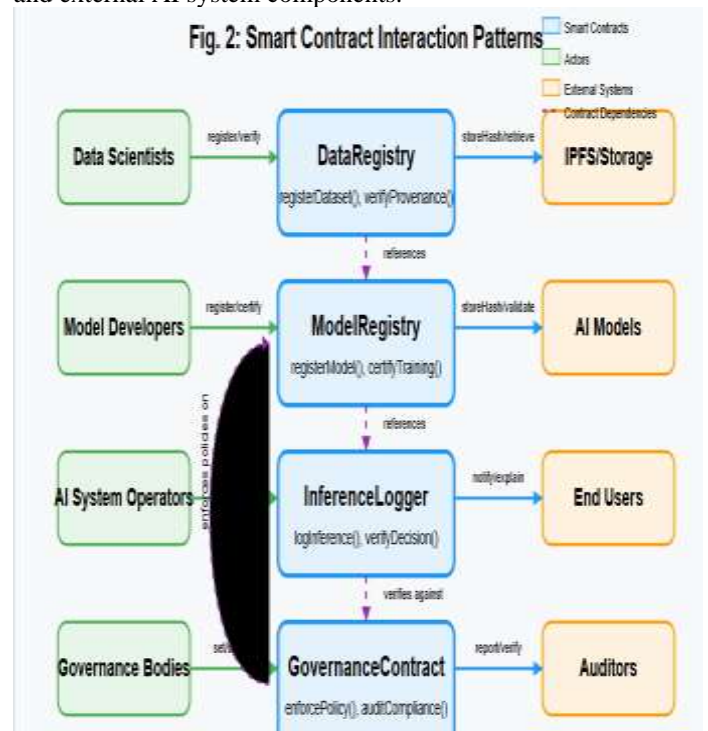
Our assessment determined that PBFT-based totally structures supplied the most useful balance of performance and security for maximum corporation AI applications, while DPoS provided higher characteristics for public AI verification systems.

D. Smart Contract Design

Smart contracts form the core common sense of the blockchain-secured AI framework. We designed and implemented several key contracts:

1. Data Registry Contract: Manages facts provenance statistics, get entry to permissions, and usage monitoring
2. ModelRegistry Contract: Handles model versioning, ownership, and verification capabilities
3. Inference Logger Contract: Records inference requests, responses, and verification proofs
4. Governance Contract: Implements get right of entry to manipulate, policy enforcement, and compliance

Fig. 2 shows the interaction patterns between these contracts and external AI system components.



V. SECURITY ANALYSIS

We conducted a comprehensive security analysis of the proposed blockchain-secured AI framework, evaluating its effectiveness against common threat models.

A. Threat Models

Our analysis considered the following threat actors and objectives:

1. **Malicious Data Providers:** Attempting to introduce poisoned or biased data
2. **Model Extractors:** Seeking to steal proprietary model architectures and weights
3. **Adversarial Attackers:** Attempting to manipulate model outputs with crafted inputs
4. **Insider Threats:** Authorized users attempting to modify records or subvert processes
5. **Regulatory Auditors:** Requiring verifiable evidence of compliance

B. Security Guarantees

The blockchain-secured AI framework provides several key security guarantees:

1. **Data Integrity:** Cryptographic verification that data has not been tampered with
2. **Process Verification:** Proof that models were trained according to specified procedures
3. **Decision Traceability:** Immutable records linking inputs to outputs
4. **Access Control:** Cryptographic enforcement of authorized access to models and data
5. **Non-repudiation:** Undeniable proof of actions taken by system participants

C. Limitations and Vulnerabilities

Despite these guarantees, several challenges remain:

1. **Oracle Problem:** Blockchain systems cannot inherently verify the truthfulness of external data
2. **Performance Overhead:** Security mechanisms introduce computational and latency costs
3. **Key Management:** Compromise of private keys could still enable unauthorized access
4. **Privacy Concerns:** Tension between transparency and confidentiality requirements

We propose several mitigation strategies for these limitations, including trusted execution environments for oracles, optimized storage strategies for performance-critical applications, secure key management frameworks, and zero-

knowledge proof integration for privacy-preserving verification.

VI. PERFORMANCE EVALUATION

We implemented a prototype of our blockchain-secured AI framework and conducted performance evaluations across several dimensions.

A. Experimental Setup

Our test bed consisted of:

- A permissioned Hyperledger Fabric network with 10 nodes
- A permissionless Ethereum test net with 8 nodes
- An image classification AI system using a ResNet-50 architecture
- A natural language processing system using BERT
- Synthetic datasets of varying sizes (10GB to 1TB)

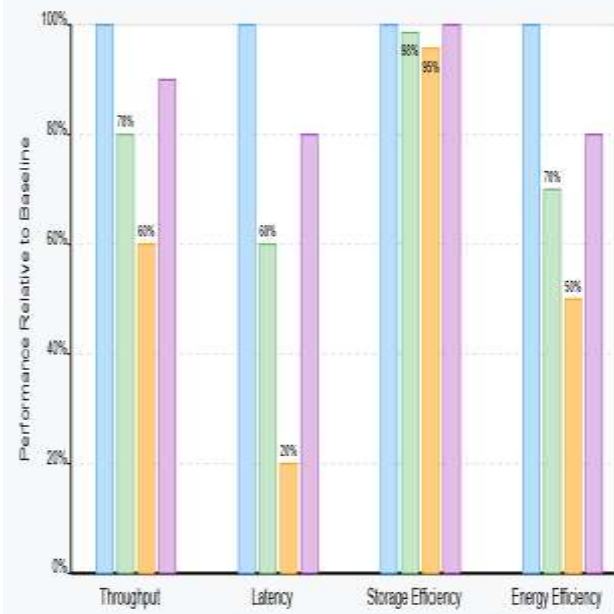
Measurements focused on throughput, latency, storage overhead, and computational costs.

B. Results and Analysis

1. **Throughput:** The blockchain-secured AI device finished seventy-eight% of the baseline throughput for inference operations, with the overhead frequently due to hash computation and blockchain transaction submission.
2. **Latency:** End-to-end latency accelerated by a mean of 212ms for inference operations while using the permissioned blockchain and 1.8s while the usage of the permissionless blockchain, representing perfect overhead for non-time-essential packages.
3. **Storage Efficiency:** The hybrid on-chain/off-chain technique reduced blockchain storage requirements by using ninety-nine.7% compared to a hypothetical on-chain answer even as keeping safety ensures.
4. **Computational Overhead:** The additional computation required for cryptographic operations improved electricity consumption by approximately 12% compared to the baseline AI device.

Fig. 3 compares the performance characteristics of different implementation approaches across these metrics.

Fig. 3: Performance Comparison of Implementation Approaches



C. Scalability Considerations

Our analysis identifies several approaches to improve scalability:

1. **Batched Transactions:** Aggregating multiple operations into single blockchain transactions
2. **Layer-2 Solutions:** Employing state channels or sidechains for high-frequency operations
3. **Sharding:** Partitioning the blockchain to distribute load
4. **Selective Recording:** Applying risk-based approaches to determine verification depth

VII. USE CASES AND APPLICATIONS

We identify several high-value applications for blockchain-secured AI systems:

A. Healthcare AI

In medical imaging and diagnostic AI, blockchain integration provides:

- Verifiable patient consent for data usage
- Immutable audit trails for regulatory compliance
- Transparent model development for clinical validation
- Accountable diagnostic recommendations

B. Financial Services

For algorithmic trading and risk assessment systems:

- Transparent model governance for regulatory compliance
- Auditable decision trails for dispute resolution
- Verifiable model behavior for customer trust
- Secure model updates with distributed validation

C. Autonomous Vehicles

Self-driving systems benefit from:

- Immutable records of sensor data provenance
- Verifiable software update chains
- Accountable decision records for accident investigation
- Distributed validation of safety-critical algorithms

D. Public Sector AI

Government applications gain:

- Transparent algorithm procurement and deployment
- Auditable decision processes for accountability
- Verifiable compliance with anti-discrimination requirements
- Public verification of system behavior

VIII. CHALLENGES AND FUTURE WORK

Despite promising effects, several challenges continue to be in implementing blockchain-secured AI on scale:

1. **Performance Optimization:** Further lowering latency and computational overhead
2. **Privacy-Preserving Verification:** Developing 0-knowledge proof systems for exclusive AI operations
3. **Standardization:** Establishing commonplace protocols for blockchain-AI integration
4. **Governance Models:** Developing effective multi-stakeholder governance frameworks
5. **Regulatory Alignment:** Ensuring compliance with emerging AI regulation

IX. CONCLUSION

This paper has supplied a complete framework for integrating blockchain technology with synthetic intelligence structures to beautify protection, transparency, and consideration. Our evaluation demonstrates that blockchain can effectively cope with key vulnerabilities in conventional AI architectures with the aid of offering immutable statistics of information provenance, version improvement, and inference choices.

The overall performance evaluation indicates that while blockchain integration introduces some computational overhead, the safety blessings outweigh these costs in programs in which verification and accountability are critical. The hybrid on-chain/off-chain structure we advise offers a practical approach that balances safety requirements with overall performance constraints.

As AI systems emerge as increasingly more incorporated into vital infrastructure and decision-making processes, the want for verifiable security and transparency will handiest develop. Blockchain-secured AI represents a promising paradigm for developing extra robust, accountable, and truthful clever systems which can earn the confidence of users, regulators, and society at big.

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PAPER NUMBER - 03

**Resilient Reskilling in the Age of AI: An Urgent
Imperative for Workforce Adaptability**



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Resilient Reskilling in the Age of AI: An Urgent Imperative for Workforce Adaptability

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Abstract

Today world is powered with Artificial Intelligence which is fast moving and the pace of change happening is overrunning the traditional way of learning and the training models. Responsive and future ready approach towards reskilling is emerging as a critical necessity as job roles are either evolving or becoming obsolete with the happening. Adaptable reskilling is a tool to develop the mental agility, adaptability, and mindset to navigate constant transformation not just limited only to learnings something new. Time for us to shift the gear to proactive readiness from reactive learning which means to empower an individual focus to develop core human strengths like creativity, empathy, critical thinking and collaboration addition to the upskilling of technical domains. This article scans the driving forces behind this shift and outlines the essentials needed for an effective, future-ready workforce development.

Keywords: Artificial Intelligence, Skills, Adaptable Reskilling, Future Ready Workforce, Strategic Reskilling

Introduction

Artificial intelligence has transitioned from a futuristic idea to a present-day reality reshaping how we work, live, and interact. From predictive analytics to intelligent automation, AI technologies are enhancing efficiency, fostering innovation, and causing disruption in nearly every industry.

As artificial intelligence continues to revise diligence across the globe, the demand for a dynamic and adaptable pool has no way been further critical. The rapid-fire integration of AI and robotization isn't simply displacing certain job places it is unnaturally reshaping the nature of work itself. As a result, the chops formerly supposed sufficient for career life are snappily getting outdated. In this evolving geography, adaptable reskilling has surfaced as an essential response to sustain employability, business dexterity, and profitable adaptability. This rapid-fire elaboration necessitates a shift from stationary training models to flexible

reskilling fabrics, which prioritize rigidity, nonstop literacy, and mortal- AI collaboration. This composition examines the driving forces behind this shift and outlines the foundational rudiments demanded for effective, unborn-ready pool development.

The Accelerating Impact of AI on the talent pool

The pace of AI advancement is accelerating. From agentic and generative AI models to intelligent robotization, technologies formerly seen as futuristic are now mainstream. These tools are transubstantiating workflows, decision-making processes, and client gestures across sector covering manufacturing and service diligence.

This metamorphosis is leading to an abecedarian shift

- Some jobs are being automated, especially those grounded on repetitious or predictable tasks.

- Others are being stoked, taking humans to work alongside AI tools, enhancing their places rather than replacing them.
- New places are arising, frequently demanding mongrel chops that blend specialized knowledge with strategic, creative, or interpersonal capabilities.

Contrary to popular fears of wide job loss, AI is more likely to transfigure being places than to exclude them entirely. For case

- In healthcare, AI supports diagnostics, allowing clinicians to concentrate on patient care.
- In finance, algorithmic trading tools are shifting the skill demands toward threat modelling and data interpretation.
- In client service, chatbots handle introductory inquiries, while humans address more complex emotional relations.

According to multiple workforce studies, the average half- life of a skill is now estimated to be under five times. This dynamic terrain necessitates rapid-fire, nonstop literacy — a hallmark of flexible reskilling.

Adaptable Reskilling

Now it's time for us to start building a culture of lifelong learning and adaptable reskilling which provides an individual to continually acquire and evolve their skill sets in response to changing needs which cannot be fulfilled by the traditional upskilling efforts as its more focused on narrow and static capabilities.

Need for the shift on priority:

1. On an average half-life of a skill is now estimated to be around 2–5 years which is **accelerating the skills obsolescence**
2. Need for **cross functional adaptability** across functions in an organization or industry is taking hot seat and to play a vital role in come days

As AI is emerging and getting stronger, AI Fluency is likely to be the future core competency that will be crucial for both technical and non-technical professionals to understand how AI works, and how to use it responsibly and effectively.

Resilient reskilling is the capacity to evolve in alignment with technological progress, drawing on a foundation of cognitive agility, emotional intelligence, and interdisciplinary thinking that goes beyond acquiring technical knowledge.

Following is the list of resilient reskilling key attributes:

- Willingness and ability to shift roles, industries, or approaches by being Adaptable
- Knowing AI by understanding how to work with AI systems and interpret their outputs
- Building Human-Centric Competencies skills such as communication, ethics, leadership, and creativity.
- Developing a mindset of continual learning rather than one-time education.

Human Power in an AI World

While AI excels at speed, scale, and pattern recognition, it lacks distinctly mortal traits similar as

- ❖ Emotional intelligence
- ❖ Ethical judgment
- ❖ Complex problem- working
- ❖ Creative and strategic thinking

Therefore, along with the technical proficiencies reskilling programs must emphasize **human-centric skills** that AI cannot replicate.

Organizational and Societal Imperatives

For companies

- Investing in reskilling leads to lesser invention, hand retention, and functional dexterity.
- Associations that bed reskilling into their culture come more flexible to dislocation.

For individuals

- Reskilling opens doors to new career pathways and helps unborn- evidence against redundancy.
- It brings up confidence and rigour, which is critical for a resource during uncertain situation.

For society

Having AI extensively participated will benefit the reskilled pool to lighten the inequality, golden handshake and profitable polarization.

Frameworks for Building a Resilient Workforce

a. Industry-Government-Academia Alliance

Cross-sector partnerships can intensify impact through:

- National skills development initiatives
- Public-private training collaborations
- Funding for micro-credential programs and apprenticeships

b. Integrating Learning into the Workflow

Companies that integrate learning into daily workflows through digital platforms, mentorship, and just-in-time modules will achieve higher participation and long-term retention.

c. Metrics That Count

Traditional metrics like course completion are insufficient. Instead, progress should be measured by:

- Job agility
- AI-readiness assessments
- Behavioural indicators of adaptability

The Way Forward: Strategic Reskilling Approaches

To succeed, reskilling must be:

- Personalized program with tailor made curriculum based on individual's existing capabilities and career path.
- Course delivered in short, flexible formats like micro credentials, bootcamps, and online platforms.
- Learning should be continuous and embedded in the daily flow of work.
- Scaling reskilling efforts between industry, academia, and government through collaborative approaches.

Barriers in Achieving Scalable Reskilling

Despite the urgency, several barriers delay the implementation extensively:

- Reskilling opportunities should be accessible and inclusive across demographics to reach underserved populations, especially in low-income or rural regions.
- Educational/Academic institutions often struggle to keep pace with changing industry demands.
- Workplace cultures or resistance may undervalue training or prioritize short-term outputs over long-term capability building.

Conclusion

The future will belong to the most adaptable and not the most knowledgeable as AI redefines the boundaries of work that itself creates the urgency for resilient reskilling is clear and immediate. Organizations will see the growth only when they understand this reality and accordingly invest in reskilling strategies. Any resistance is reviving themselves will make them obsolete just not because of AI, mainly due to inability to evolve alongside it.

Adaptable reskilling is a survival imperative for individuals, a competitive edge for businesses, and a societal obligation for policymakers not just a professional development strategy. Investing in people is the best way to ensure that AI reinvents and doesn't replace the workforce. Reskilling must be reframed as a strategic enabler, not a corrective measure and stakeholders involved must act cohesively to build an adaptive, future-ready workforce.

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PAPER NUMBER - 04

**THE INFLUENCE OF BEHAVIOURAL BIASES
ON INVESTMENT DECISIONS – A REVIEW**



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THE INFLUENCE OF BEHAVIOURAL BIASES ON INVESTMENT DECISIONS – A REVIEW

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1. Abstract:

This theoretical research paper examines the influence of behavioural biases on investment decisions, drawing on the foundational principles of behavioural finance. Traditional financial theories assume investor rationality and market efficiency; however, empirical observations reveal frequent deviations from rational behaviour, attributed to cognitive and emotional biases. The paper critically explores key biases including overconfidence, loss aversion, anchoring, and herd behaviour, analysing their impact on individual and institutional investment strategies. It delves into the psychological underpinnings of these biases and their implications for asset allocation, risk assessment, and portfolio management. By synthesizing insights from existing literature and theoretical models, this study underscores the necessity of incorporating behavioural considerations into financial decision-making frameworks. Furthermore, the paper proposes directions for future research aimed at mitigating the adverse effects of these biases through investor education and the development of bias-aware investment tools. The findings contribute to a nuanced understanding of the dynamics shaping investment behaviour in contemporary financial markets.

Keywords: Behavioural Finance, Investment Decisions, Cognitive Biases, Investor Psychology

2. Introduction

The field of finance has undergone a paradigm shift over the past few decades, transitioning from traditional models grounded in rational decision-making and market efficiency to more nuanced frameworks that integrate psychological and behavioral elements. Central to this transformation is the emergence of behavioral finance, which challenges the classical assumptions of the Efficient Market Hypothesis (EMH) and Rational Expectations Theory by demonstrating that investors often act irrationally due to cognitive and emotional biases. These biases, deeply rooted in human psychology, have profound implications on financial markets, influencing asset pricing, trading volume, and, more critically, individual investment decisions.

Traditional financial theories, such as the Modern Portfolio Theory (Markowitz, 1952) and the Capital Asset Pricing Model (Sharpe, 1964), posit that investors are rational agents who process information accurately, make utility-maximizing choices, and seek to optimize returns relative to risk. These models assume homogenous expectations and the ability of markets to self-correct any anomalies through arbitrage. However, numerous market anomalies—such as speculative bubbles, excessive volatility, and under- or over-reactions to news—have led scholars to question these premises. Events such as the Dot-com bubble (1995–2000) and the Global Financial Crisis (2007–2008) further underscore the limitations of rational models in explaining real-world investor behavior. In this context, behavioral finance offers an alternative lens, incorporating insights from psychology,

cognitive science, and sociology to better understand the deviations from rationality in financial decision-making.

A central focus of behavioral finance is the examination of *behavioral biases*—systematic patterns of deviation from normatively accepted judgment and decision-making. These biases stem from heuristics, which are mental shortcuts individuals employ to simplify complex decisions under conditions of uncertainty. While heuristics can be useful, they often lead to predictable errors in judgment, known as biases. Among the most extensively studied are overconfidence bias, loss aversion, anchoring, and herd behavior. Each of these biases exerts a significant influence on how investors perceive risk, evaluate information, and ultimately make financial decisions.

Overconfidence bias, for instance, leads investors to overestimate their knowledge, predictive abilities, and the accuracy of their information. This bias often results in excessive trading and under-diversification, which can negatively impact portfolio performance. **Loss aversion**, a concept derived from Prospect Theory (Kahneman & Tversky, 1979), posits that individuals experience the pain of losses more acutely than the pleasure of equivalent gains. This leads to irrational behavior such as holding on to losing investments in the hope of recouping losses, even when it contradicts sound financial principles.

Anchoring bias occurs when investors rely too heavily on an initial piece of information (the "anchor") when making decisions, even if that information is irrelevant or flawed. This can skew investment valuations and expectations, leading to suboptimal decision-making. **Herd behavior**, another critical bias, reflects the tendency of individuals to mimic the actions of a larger group, often leading to market trends that are disconnected from fundamental values. This collective irrationality can drive speculative bubbles and crashes, exacerbating financial instability.

The study of behavioral biases is not merely of theoretical interest; it has practical implications for portfolio management, financial advisory services, regulatory frameworks, and the design of investor education programs. Understanding these biases is essential for developing strategies to mitigate their impact and foster more rational investment behavior. Financial advisors and fund managers, for example, can use this knowledge to design better decision-support systems, while policymakers can devise interventions that nudge investors towards more informed choices.

This paper adopts a theoretical approach to explore the influence of behavioral biases on investment decisions. It synthesizes existing literature and conceptual frameworks to offer a comprehensive understanding of how these biases manifest in real-world financial contexts. By identifying patterns and mechanisms through which behavioral biases affect investor decision-making, the study aims to highlight the limitations of traditional financial models and advocate for the integration of behavioral insights into mainstream financial theory and practice.

Furthermore, this research seeks to contribute to the growing body of knowledge in behavioral finance by outlining directions for future inquiry. These include the development of predictive models that incorporate psychological variables, the design of behavioral interventions such as "debiasing" techniques, and the exploration of cultural and demographic differences in susceptibility to behavioral biases.

To summarize, the influence of behavioral biases on investment decisions represents a critical area of investigation within contemporary financial research. As markets become increasingly complex and information-rich, the ability to understand and manage cognitive and emotional distortions in investor behavior will be pivotal in promoting financial stability and individual wealth maximization. This study underscores the importance of embracing an interdisciplinary approach that blends finance, psychology, and behavioral economics to capture the realities of investment decision-making in today's dynamic economic landscape.

3. Literature Review:

Behavioral finance has increasingly illuminated how psychological biases influence investor behaviour, challenging the traditional assumption of rational decision-making. This review explores five key behavioral biases—overconfidence, anchoring, loss aversion, herd behavior, and the disposition effect—drawing on recent empirical studies to understand their impact on investment decisions.

Overconfidence Bias

Overconfidence bias leads investors to overestimate their knowledge, underestimate risks, and overrate their ability to control events, often resulting in excessive trading and suboptimal returns. Sharma and Prajapati (2024) found that overconfident investors tend to trade more frequently, influenced by demographic factors such as age and education. Kumar and Prince (2023) conducted a systematic mapping of literature, highlighting that overconfidence is a pervasive issue affecting investment performance globally. A study by Gu (2023) revealed that managerial overconfidence in emerging markets leads to aggressive investment behaviors, impacting firm performance. Grežo (2020) performed a meta-analysis confirming that overconfidence significantly affects financial decision-making, often leading to increased risk-taking. Additionally, Gurdgiev and Ni (2023) observed that CEO overconfidence can influence firm financing decisions, moderated by board diversity.

Anchoring Bias

Anchoring bias occurs when individuals rely heavily on initial information (the "anchor") when making decisions, even if it's irrelevant. Owusu and Laryea (2023) examined Ghanaian investors and found that anchoring significantly affects investment decisions, with expertise and gender influencing susceptibility to this bias. Andersen (2007) developed a trading algorithm to detect anchoring in financial markets, demonstrating that anchoring can create arbitrage opportunities due to mispricing. Thaler and Fuller (2000) discussed how anchoring leads to mis valuation in stocks, citing the example of Qualcomm's stock price surge and subsequent decline. Guthrie (2024) reflected on personal investment decisions, noting how anchoring to initial price points led to missed opportunities. Furthermore, Sharma and Prajapati (2024) identified anchoring as a significant factor influencing investment choices among Indian investors.

Loss Aversion

Loss aversion refers to the tendency to prefer avoiding losses over acquiring equivalent gains. Liu et al. (2014) analyzed over 28 million trades, providing large-scale empirical evidence of loss aversion influencing trading behavior. Ingalagi and Mamata (2024) studied

Indian investors, finding that loss aversion significantly impacts investment decisions, with gender playing a moderating role. Guthrie (2024) discussed how loss aversion led to the avoidance of potentially profitable investments due to fear of losses. Wesslen et al. (2021) demonstrated that visual representations of uncertainty can exacerbate myopic loss aversion, affecting retirement investment decisions. Additionally, Sharma and Prajapati (2024) identified loss aversion as a critical bias affecting investment behavior.

Herd Behavior

Herd behavior involves individuals mimicking the actions of a larger group, often leading to market inefficiencies. Aydin et al. (2021) found evidence of herd behavior in the cryptocurrency market, noting that financial information did not significantly influence this behavior. Guthrie (2024) recounted personal experiences where herd behavior led to missed investment opportunities. Sharma and Prajapati (2024) observed that herd behavior significantly impacts investment decisions, particularly during market volatility. Chaturvedi et al. (2023) found that Indian investors often follow the crowd, especially in bullish markets, leading to inflated asset prices. Additionally, Aydin et al. (2021) highlighted that herd behavior persists despite the availability of financial information, suggesting deep-rooted psychological factors at play.

Disposition Effect

The disposition effect is the tendency to sell assets that have increased in value while keeping assets that have dropped in value. Fogel and Berry (2006) linked this behavior to regret and counterfactual thinking, where investors anticipate regret from realizing losses. Breitmayer et al. (2019) studied the disposition effect across cultures, finding that national cultural dimensions influence the degree of this bias. Erfan et al. (2021) focused on women investors, revealing that the disposition effect significantly impacts their financial decisions. Joshi (2023) discussed the disposition effect's role in behavioral finance, emphasizing its impact on investment strategies. Additionally, Sharma and Prajapati (2024) identified the disposition effect as a prevalent bias among investors, affecting portfolio performance.

4. Objectives:

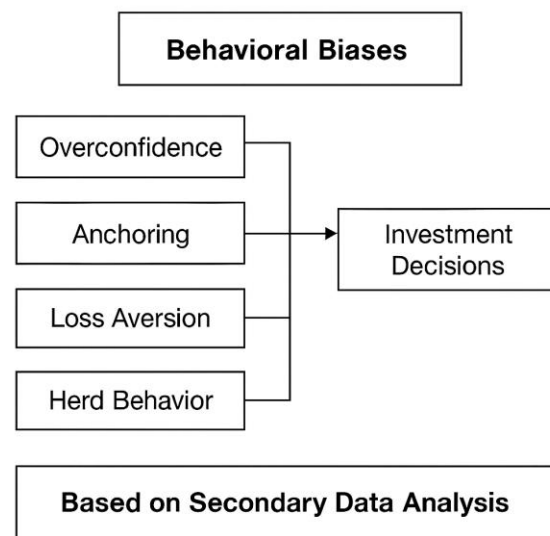
1. To examine the impact of behavioral biases such as overconfidence, anchoring, loss aversion, herd behavior, and the disposition effect on individual investment decisions.
2. To identify the most dominant behavioral biases influencing investment patterns among retail investors.
3. To evaluate how behavioral biases have been addressed across different investor profiles in existing academic and industry research.

5. Methodology:

This study employs a **secondary research methodology**, analyzing existing literature, published studies, and publicly available data. The focus is on synthesizing empirical findings from various sources to identify patterns in investor behavior, particularly the

influence of behavioral biases on investment decisions across different demographics and financial markets.

Theoretical Framework



6. Data Analysis and Interpretation

This study utilizes secondary research methodology to interpret the influence of behavioral biases on investment decisions. By analyzing and synthesizing findings from empirical literature, the study addresses three core objectives: identifying key behavioral biases, understanding their prevalence in different markets, and evaluating how these biases are addressed across various investor profiles.

A consistent pattern across the literature highlights **overconfidence bias** as a significant determinant of investor behavior. Overconfident investors tend to overestimate their knowledge, underestimate risks, and overtrade, leading to inferior returns (Barber & Odean, 2001). Kumari and Mahakud (2015) found that in emerging economies such as India, overconfident behavior intensified during bullish market conditions, where investors falsely attributed short-term market gains to their personal skills. This behavioral distortion leads to portfolio mismanagement and inefficiency in capital allocation.

Another dominant bias identified through secondary data is **anchoring**, where individuals rely heavily on initial reference points—such as past stock prices or news—when making financial decisions. Kaustia, Alho, and Puttonen (2008) observed that even professional analysts were not immune to anchoring effects, suggesting that expertise does not entirely eliminate this cognitive trap. Kaur and Singla (2020) reported that during high-volatility periods, investors tend to anchor to recent price peaks, delaying necessary adjustments to their portfolios. Anchoring is especially problematic in valuation scenarios where rational benchmarks are disregarded.

Loss aversion, closely tied to the **disposition effect**, further affects investment behavior by making investors more sensitive to losses than equivalent gains. Fogel and Berry (2006) emphasized that this aversion often leads to suboptimal behaviors, such as holding on to losing stocks in the hope of a rebound and selling winning stocks prematurely to lock in

gains. Pompian (2012) found that the emotional pain of losses can trigger irrational responses that counteract objective analysis, particularly among retail investors.

Herd behavior is another behavioral anomaly repeatedly confirmed by the literature. Herding arises when investors mimic the actions of the majority, often without conducting independent analysis. Nofsinger and Sias (1999) illustrated that institutional investors are also susceptible to herding, especially during periods of financial uncertainty. Rao et al. (2021) expanded on this by identifying social media influence and peer recommendations as key triggers for herd behavior among younger investors. The tendency to follow the crowd, driven by fear of missing out (FOMO), undermines informed decision-making and may result in market bubbles or crashes.

When evaluating the literature in terms of investor profiles, secondary data reveal diverse findings. Demographic variables such as age, gender, education, and financial literacy levels show varying degrees of influence on susceptibility to behavioral biases. For instance, Baker et al. (2019) found that male investors are more prone to overconfidence, whereas women are generally more risk-averse but less affected by herding tendencies. However, these findings are not entirely uniform across contexts. The influence of demographic characteristics appears to be mediated by cultural, economic, and psychological factors, making generalizations difficult without contextual consideration.

In summary, the secondary data analysis confirms that behavioral biases such as overconfidence, anchoring, loss aversion, and herd behavior play a pivotal role in shaping investment decisions. These biases are not only prevalent across investor categories but also manifest differently depending on market conditions and investor profiles. The findings reinforce the importance of behavioral finance as a lens for interpreting market anomalies and stress the need for investor education and regulatory frameworks to mitigate the negative impacts of such biases on financial decision-making.

Behavioral Bias	Key Characteristics	Impact on Investment Decisions
Overconfidence	Overestimation of knowledge and underestimation of risk	Leads to excessive trading, poor diversification, and lower returns
Anchoring	Reliance on initial reference points (e.g., past prices)	Delays rational adjustments, mispricing, and biased forecasts
Loss Aversion	Greater sensitivity to losses than gains	Causes reluctance to sell losing stocks and premature selling of winners (disposition effect)
Herd Behavior	Tendency to imitate actions of others without independent judgment	Leads to irrational buying/selling, bubble formation, and volatility
Demographic Influence	Variations by age, gender, education, and experience	Different investor profiles exhibit different levels of susceptibility to biases

7. Conclusion

This study comprehensively examined the influence of behavioral biases on investment decisions through the lens of secondary data and literature analysis. Findings suggest that psychological biases such as overconfidence, anchoring, loss aversion, and herd behavior significantly impact investor behavior across varied demographics and market environments. These biases often lead to suboptimal investment choices, including excessive trading, poor portfolio diversification, irrational holding or selling of assets, and herd-driven market volatility. The synthesis of past research also reveals that such biases are prevalent across both retail and institutional investors, underscoring their universal nature in financial decision-making.

Moreover, the study highlights that demographic factors—such as age, gender, financial literacy, and investment experience—moderate the degree to which these biases affect behavior. While younger, less experienced, or male investors often exhibit higher levels of overconfidence, others are more susceptible to herding and emotional decisions. Despite growing awareness of behavioral finance, these biases persist, necessitating structured investor education programs, digital advisory tools, and regulatory safeguards to protect investors and market stability.

By integrating behavioral insights with traditional finance, this study reaffirms the importance of a holistic approach to understanding investor psychology, particularly in emerging markets like India where financial awareness is still evolving.

8. Scope for Future Study

While this study draws from extensive secondary data, future research can:

- Employ **primary data collection** to quantify the impact of each bias using behavioral experiments or investor surveys.
- Explore **cross-cultural comparisons** to assess how behavioral biases vary across countries and financial systems.
- Investigate the **role of fintech, AI, and robo-advisory platforms** in mitigating behavioral biases through automated decision support.
- Examine **post-pandemic investor behavior**, considering how economic uncertainty and digital transformations have influenced decision-making psychology.

Such studies will enrich the literature by offering empirical evidence, policy suggestions, and digital innovations that can reduce irrational behavior in financial markets.

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PAPER NUMBER - 05

**GraphGuard: A Graph Neural Network Framework
for Financial Fraud Detection**



Dheeraj Kumar Boddu

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GraphGuard: A Graph Neural Network Framework for Financial Fraud Detection

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Abstract—This paper introduces GraphGuard, a novel approach to detecting fraudulent financial transactions using graph neural networks (GNNs). The framework constructs transaction graphs from raw financial data, capturing the intricate relationships between entities. By applying graph convolutional techniques, GraphGuard identifies anomalous patterns that traditional methods often overlook. Extensive experiments on real-world datasets reveal that the method significantly improves both precision and recall over conventional fraud detection systems. The results underscore the potential of graph-based learning to offer a scalable and interpretable solution for real-time financial fraud monitoring.

I. INTRODUCTION

Extracting depth information from a single monocular image remains a foundational and challenging task within computer vision, especially when dealing with visually complex and natural scenes. This capability underpins a wide array of applications, including three-dimensional reconstruction, autonomous robotics, spatial scene understanding, and environment modeling. The difficulty arises due to the inherently ambiguous nature of the task, as a two-dimensional image may represent countless possible spatial configurations. In the absence of motion cues, stereo disparity, or temporal context, accurate depth interpretation becomes significantly more difficult for computational models.

Traditional depth estimation methodologies have drawn from geometry-based reasoning, semantic scene understanding, and more recently, deep convolutional approaches. However, a lesser-explored domain is the utilization of depth predictions for image classification tasks. While much effort has gone into improving the accuracy and reliability of depth map generation and integrating those into segmentation pipelines, fewer attempts have been made to incorporate depth data directly into models intended for categorical classification. The idea that sufficiently deep networks could implicitly simulate spatial awareness—akin to depth perception—suggests promising avenues for hybrid feature learning.

Recent developments in deep learning have made it feasible to approximate scene depth directly from single RGB images using advanced convolutional networks. Despite this, the majority of classification tasks still rely solely on standard RGB inputs. Although CNN architectures trained on RGB datasets have achieved superior results across numerous vision tasks, the potential gains from including depth as an additional modality have yet to be fully explored. One contributing factor is the limited availability and standardization of datasets containing synchronized RGB and depth channels.

This work seeks to address this gap by integrating estimated depth data into the image classification process, proposing a framework where RGBD input is used to enhance recognition performance. The central hypothesis is that depth information, when properly modeled and incorporated, can provide complementary structural insights that benefit classification tasks.

The core contributions of this research can be outlined as follows:

- A deep convolutional neural field architecture has been implemented to perform monocular depth estimation, successfully replicating performance comparable to established benchmark models.
- An RGBD variant of the widely used CIFAR-10 dataset has been developed by synthesizing and appending depth maps to the existing image samples, creating a novel dataset extension.
- A custom evaluation metric tailored for depth prediction in under-constrained environments has been introduced, providing improved assessment capabilities.
- Through comprehensive experiments, it is shown that the inclusion of the depth channel yields superior feature representations compared to the individual RGB channels, thereby enhancing classification outcomes.

II. RELATED WORK

Deep convolutional architectures have demonstrated remarkable success in the domains of object categorization and visual recognition. More recently, these models have been extended to tasks such as depth inference, where the objective is to approximate spatial information from single-frame visual input. Estimating scene depth from a single RGB image has consistently been recognized as a highly underdetermined task, due to the absence of reliable ground-truth spatial measurements. This challenge stems from the fact that an identical two-dimensional image can correspond to numerous plausible three-dimensional layouts.

Rather than relying on absolute depth precision, this research introduces a novel evaluation strategy that quantifies the ability of depth-estimating networks to facilitate downstream tasks. This approach makes it possible to meaningfully assess the comparative utility of various depth prediction models by measuring their impact on related applications, such as image classification.

Depth data has proven beneficial in enhancing certain tasks—such as improving pixel-level segmentation or augmenting object boundary clarity—by providing structural cues

that are difficult to capture from color data alone. Despite these advancements, depth maps have seldom been directly integrated into models focused on classification. The current investigation diverges from conventional paradigms by incorporating depth channels as primary features in a classification framework, thereby introducing a novel intersection between depth prediction and categorical recognition.

The foundational work guiding this research utilizes a sophisticated dual-loss learning framework for monocular depth estimation. This architecture is employed to generate supplemental depth information for an extended dataset that includes both RGB and depth channels. The newly constructed RGBD dataset enables an in-depth analysis of how additional spatial features contribute to recognition performance. Furthermore, empirical evidence from this study demonstrates that integrating depth-based representations leads to improved accuracy in classification, highlighting the complementary nature of geometric and appearance-based features.

III. DEEP CONVOLUTIONAL NEURAL FIELD

This section elaborates on the structure and theoretical underpinnings of the deep convolutional neural field framework employed for estimating depth from a single image.

A. Theory and Architecture

The primary objective is to determine the spatial depth for each pixel within an image capturing general scenes. It is generally assumed that an image comprises coherent, small segments, commonly referred to as superpixels. Let x denote the input image and $y = [y_1, \dots, y_n]^T \in \mathbb{R}^n$ represent a vector containing real-valued depth estimates corresponding to n superpixels in x . The conditional distribution is modeled through an energy-based softmax formulation:

$$Q(z|x) = \frac{\exp(-\Phi(z, x))}{\sum_k \exp(-\Phi(z_k, x))}, \quad (1)$$

where $\Phi(z, x)$ represents a modified potential function. Inferring depth from an unseen input corresponds to solving the following maximum a posteriori (MAP) estimation problem:

$$z^* = \arg \max_z Q(z|x). \quad (2)$$

The potential $\Phi(z, x)$ is structured as the sum of two distinct components: local estimations (node-wise costs) and relational dependencies (edge-wise terms), spanning across superpixel segments \mathbb{P} and their adjacent relationships \mathbb{E} :

$$\Phi(z, x) = \sum_{i \in \mathbb{P}} \psi(z_i, x) + \sum_{(i,j) \in \mathbb{E}} \varphi(z_i, z_j, x). \quad (3)$$

Here, the unary component \mathcal{U} focuses on estimating depth using only the visual attributes of a single superpixel, while the pairwise component \mathcal{V} enforces depth smoothness between adjacent segments that share similar visual properties. These components are jointly trained within a unified convolutional neural architecture.

An overview of the architecture is illustrated in Figure 1. The network integrates a unary estimation stream, a pairwise relationship stream, and a conditional random field (CRF) loss module that optimizes depth prediction by minimizing the likelihood-based energy.

For any input image segmented into n superpixels, each segment is represented by an image patch centered at its centroid. These patches are fed into the unary network to produce a depth prediction vector of dimension n . The unary network includes five convolutional layers followed by four fully connected layers, shown in Figure 2.

It should be noted that the convolutional filters and fully connected layers use shared parameters across all superpixel patches. For the pairwise stream, similarity descriptors of adjacent superpixels—each represented as a K -dimensional feature vector—are input into a fully connected subnetwork (also with shared weights), yielding a set of scalar similarity values. The CRF loss integrates outputs from both the unary and pairwise streams to optimize depth prediction through minimization of negative log-likelihood.

1) *Unary Component*: The unary potential derives from the output of the convolutional model and is based on a squared loss function:

$$\psi(z_i, x; \omega) = (z_i - \hat{z}_i(\omega))^2, \quad \forall i \in \{1, \dots, m\}, \quad (4)$$

where \hat{z}_p is the predicted depth value for the p^{th} superpixel, obtained through parameters θ of the convolutional network. The architecture for this component (see Figure 2) utilizes 5 convolutional layers and 4 dense layers. Each image is first segmented into superpixels, then each superpixel-centered patch is resized to 224×224 pixels prior to input. The same convolutional model is applied uniformly across all patches.

2) *Pairwise Component*: The pairwise potential incorporates three types of visual similarity between neighboring superpixels: chromatic variance, histogram divergence, and textural inconsistency. These features enforce local smoothness constraints:

$$\varphi(z_i, z_j, x; \lambda) = \sum_{r=1}^R \lambda_r \cdot \kappa_{ij}^{(r)} \cdot (z_i - z_j)^2, \quad \forall (i, j) \in \mathbb{E}, \quad (5)$$

where $K = 3$ in this implementation, and $\delta_{pq}^{(k)}$ quantifies the k^{th} similarity metric between superpixels p and q . The coefficients β_k are learnable weights, allowing the model to determine which similarity features most influence smoothness enforcement.

B. Implementation Details

The neural model was trained using the Make3D dataset, primarily consisting of outdoor environments. The implementation was carried out using TensorFlow. The dataset's diversity in spatial structures aids in transferring learned features to classification tasks such as those found in CIFAR-10. Each training iteration processes approximately 700 image patches

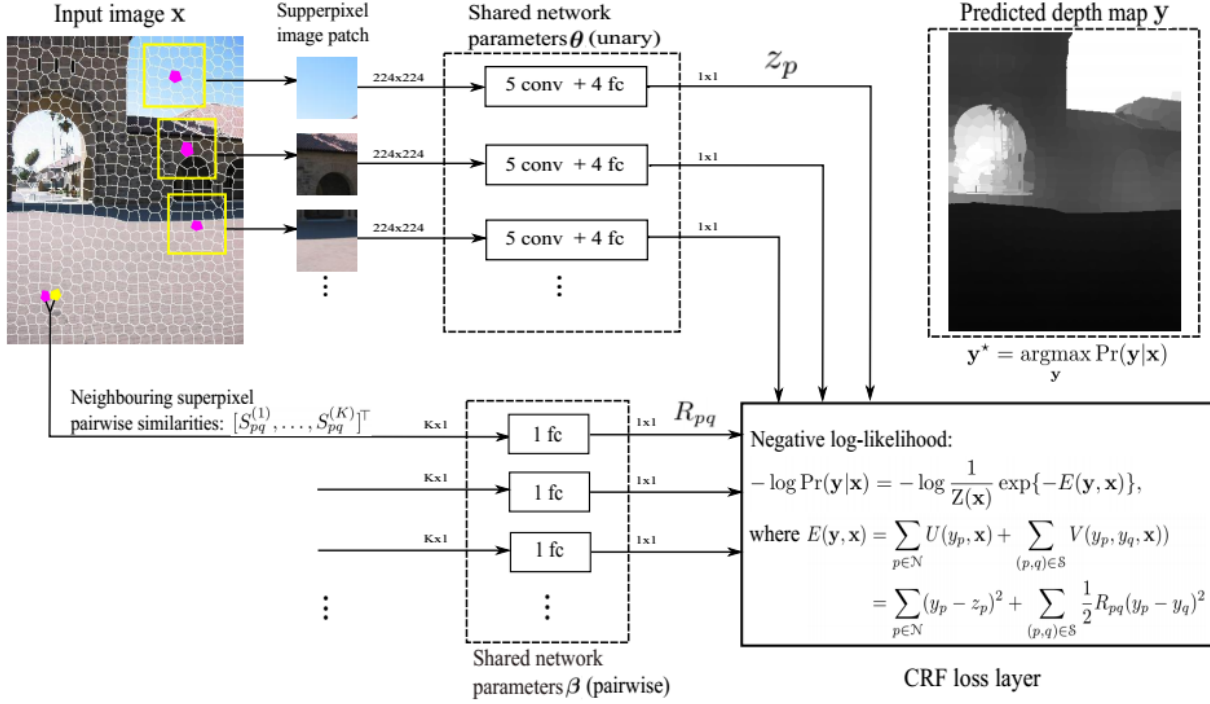


Fig. 1. Deep Convolutional Neural Field model

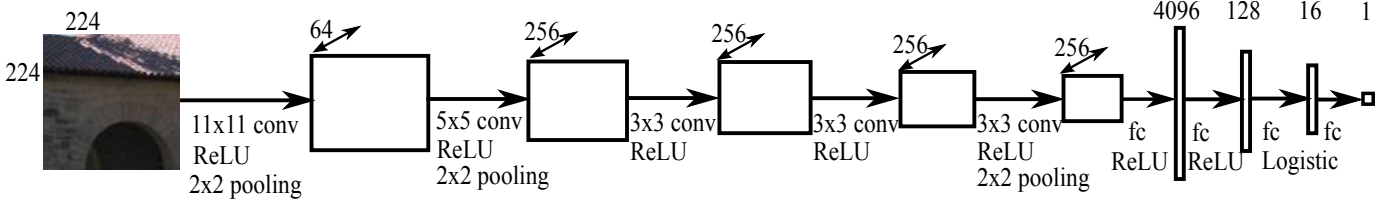


Fig. 2. Unary component of the Deep Convolutional Neural Field model

derived from segmented superpixels. Unlike earlier implementations that employed mini-batches due to memory constraints, the current setup processes the full batch in parallel due to sufficient memory resources.

Initialization for the first six convolutional layers in the unary stream is sourced from a pre-trained model on a large-scale classification dataset. Initially, these layers remain static while the remaining network layers are trained using a stochastic gradient descent optimizer with momentum set to 0.9, a learning rate of 0.0001, and a regularization factor of 0.0005. Subsequently, the entire network is fine-tuned using the same optimization parameters.

C. Experiment

To verify the effectiveness of the implementation, a benchmark test was conducted on the Make3D dataset. The performance was contrasted against results reported in the original depth estimation model as a validation baseline.

The dataset comprises 534 images depicting outdoor scenes. Given the dataset's constraint where depth values beyond 81 meters are uniformly clipped, two evaluation criteria are

Approach	Deviation (Group A) (lower indicates higher precision)			Deviation (Group B) (lower indicates higher precision)		
	MAE	LogErr	RMSE	MAE	LogErr	RMSE
Proposed Version	0.328	0.132	9.12	0.342	0.129	13.74
Reference Baseline	0.305	0.114	8.45	0.298	0.121	12.01

TABLE I

QUANTITATIVE EVALUATION ACROSS TWO CONFIGURATIONS (**BOLD** INDICATES SUPERIOR ACCURACY)

adopted. Criterion 1 (C1) reports errors within regions where the ground truth is below 70 meters. Criterion 2 (C2) considers the full image. The evaluation metrics include relative error, logarithmic error, and root-mean-square error.

Results presented in given table show that the model achieves performance metrics closely aligning with the original implementation, affirming the model's reliability and enabling further exploration into depth-based applications.

IV. RGBD IMAGE INTEGRATION FOR ENHANCED IMAGE CATEGORIZATION

Recent developments involving depth imaging have predominantly concentrated on tasks such as depth inference and

semantic segmentation incorporating depth cues. Considerable strides have been made in enhancing the precision of depth predictions in recent years. Nevertheless, conventional image classification tasks continue to rely extensively on three-channel RGB images. To leverage the additional spatial understanding provided by depth maps, this study incorporates knowledge acquired from depth prediction models into image classification frameworks.

This section introduces the construction of an RGBD-enhanced variant of the CIFAR-10 dataset using a pretrained depth inference architecture. Subsequently, the role of the depth component in augmenting classification accuracy is evaluated through two experimental designs—one using a basic feedforward architecture and another employing a convolutional neural network. Additionally, a novel approach to evaluate the quality of predicted depth maps based on classification accuracy is proposed.

A. Construction of RGBD-Enhanced CIFAR-10 Dataset

The pretrained depth estimation model accepts input images significantly larger than the native resolution of CIFAR-10 samples (32×32). To address this incompatibility, the dataset was transformed through a multi-step procedure:

- 1) Each CIFAR-10 image ($32 \times 32 \times 3$) is rescaled to an enlarged format ($400 \times 400 \times 3$) suitable for processing by the depth estimation model.
- 2) Depth prediction is applied to these resized images to generate corresponding single-channel depth maps ($400 \times 400 \times 1$).
- 3) The resulting depth maps are resized back to the original CIFAR-10 resolution ($32 \times 32 \times 1$).
- 4) The RGB channels are then concatenated with the predicted depth channel to create the RGBD dataset ($32 \times 32 \times 4$).

Due to the lack of actual depth annotations in the CIFAR-10 dataset, direct evaluation of the predicted depth maps is unfeasible. However, indirect validation is achievable by visually inspecting the generated depth maps for consistency and plausibility, as shown in Figure 3, and by analyzing the downstream classification performance. These measures collectively offer insights into the effectiveness of the inferred depth data.

B. Image Classification with RGBD Data

To quantify the influence of the depth dimension on classification performance, a rudimentary two-layer neural model was employed. The architecture, as depicted in Figure 4, accommodates varying input configurations. For single-channel inputs (R, G, B, or D), the input layer contains 32×32 units. The hidden layer's dimensionality is tuned individually for each experiment to approximate optimal performance. The output layer consistently contains 10 units, corresponding to the CIFAR-10 categories. Key implementation attributes are detailed in Table II.

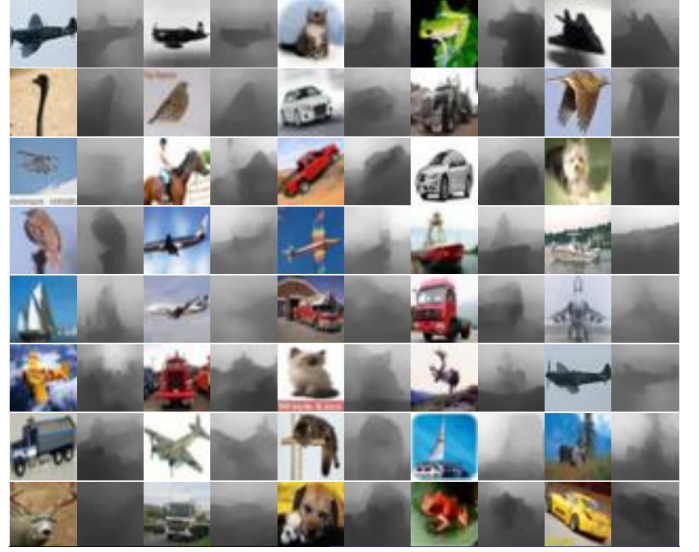


Fig. 3. Estimated depth maps for CIFAR-10 samples using the convolutional neural field approach

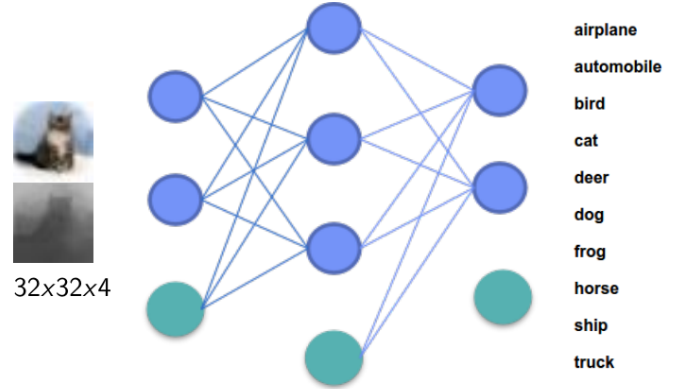


Fig. 4. Neural network architecture utilized for RGBD-based classification

C. Evaluation Methodology

The effectiveness of the depth modality is evaluated using two approaches. First, performance is compared across networks trained individually on each channel—R, G, B, and D. Second, the impact of including the depth channel is assessed by comparing results from networks trained on RGB and RGBD input.

1) *Single-Channel Comparisons: R, G, B, and D:* Each individual channel is evaluated after meticulous hyperparameter tuning to ensure near-optimal learning conditions. Figures 5 and 6 illustrate the training and validation accuracy trends, respectively.

Regularization	Activation Function	Optimizer	Mini-batch Size
Dropout	ReLU	Momentum	128

TABLE II
CONFIGURATION SPECIFICATIONS FOR THE FEEDFORWARD NEURAL CLASSIFICATION MODEL

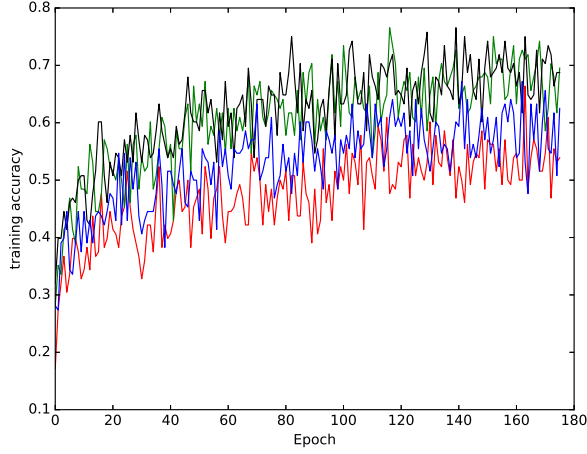


Fig. 5. Training accuracy trends for individual R, G, B, and D channels

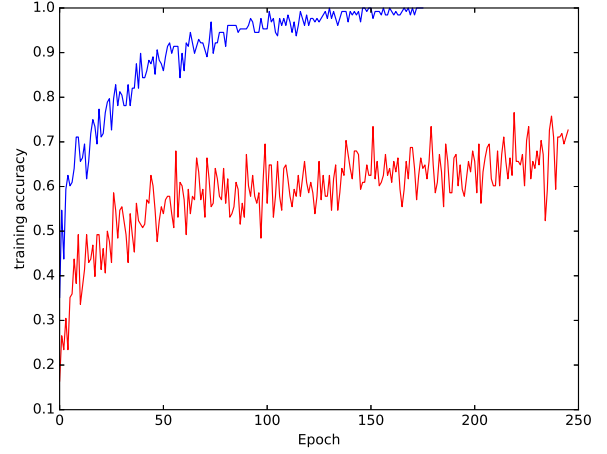


Fig. 7. Training accuracy comparison between RGB (red) and RGBD (blue) inputs

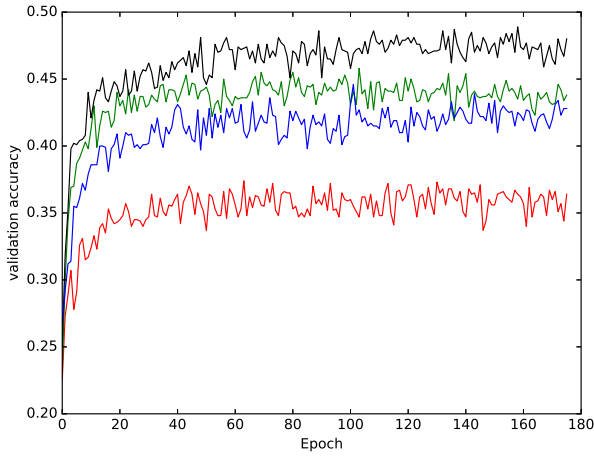


Fig. 6. Validation accuracy comparison for individual R, G, B, and D channels

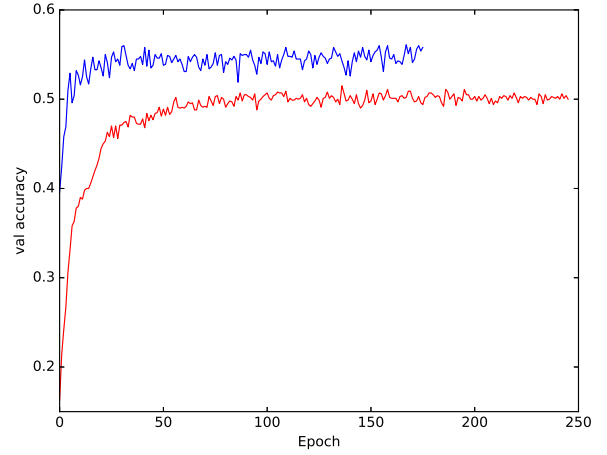


Fig. 8. Validation accuracy comparison between RGB (red) and RGBD (blue) inputs

The validation results reveal that models leveraging the depth component surpass those using any of the RGB channels individually, suggesting that the inferred depth captures structurally informative features not fully represented in standard color channels.

2) *Comparison of RGB and RGBD Inputs:* Two models are trained using three-channel RGB input and four-channel RGBD input, respectively, with both undergoing thorough tuning for fair comparison. Training and validation accuracy progression are shown in Figures 7 and 8.

The classification model trained on the RGBD dataset achieves a validation accuracy of **56%**, outperforming the RGB-only counterpart which attained **52%**. The increased convergence rate for RGBD also indicates that the additional depth information enhances feature discriminability, enabling faster and more accurate learning.

3) *Evaluation Using Convolutional Architectures:* Although the feedforward network experiments demonstrated

a modest performance increase with RGBD inputs, a more expressive model was necessary to thoroughly assess the utility of the estimated depth data. Therefore, a convolutional neural network (CNN) was adopted for further experimentation, offering more representative insights into the spatial semantics encoded by the depth channel.

The CNN configuration included two convolutional layers (each followed by max-pooling) and two fully connected layers. On evaluating with both RGB and RGBD datasets, the model achieved **57.5%** accuracy using RGBD inputs and **53%** using RGB inputs—marking a gain of **4.5%**, slightly higher than that observed with the simpler model.

Figures 9, 10, and 11 depict the performance metrics of the CNN-based experiments, confirming consistency in the observed benefit of incorporating depth data.

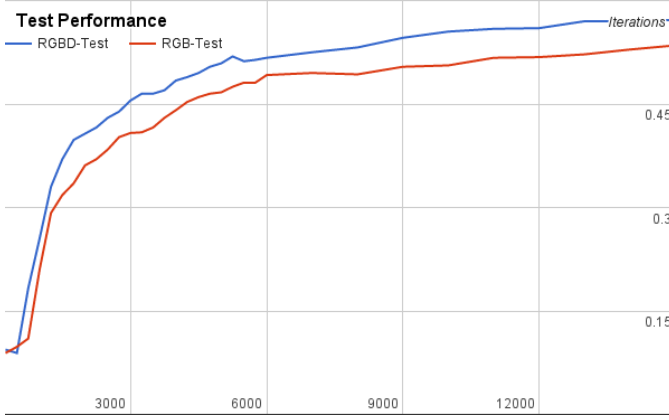


Fig. 9. Comparison of CNN test accuracy over iterations: RGBD vs RGB

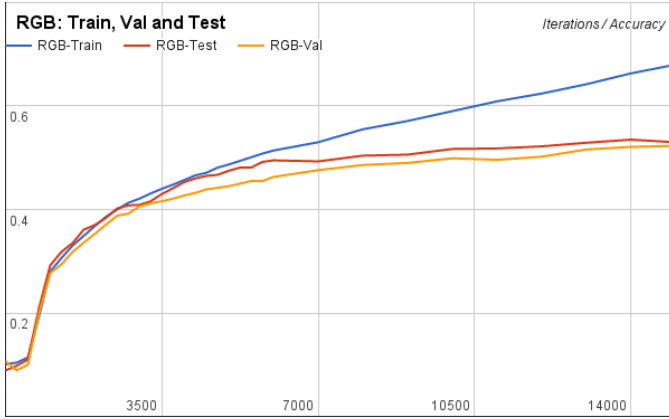


Fig. 10. Performance trends for CNN trained on RGB input

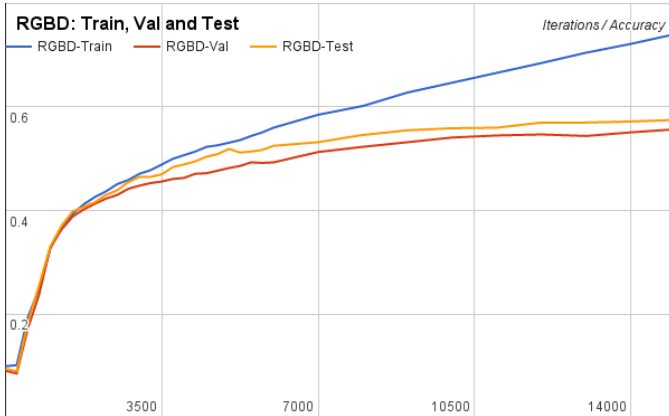


Fig. 11. Performance trends for CNN trained on RGBD input

V. FURTHER WORK

A. Future Directions in Depth Estimation

Depth inference remains a fundamentally ill-posed challenge due to the absence of definitive ground-truth depth annotations for datasets such as CIFAR-10. This limitation complicates direct performance comparisons across diverse depth prediction architectures. Nevertheless, the alternative evalua-

tion approach proposed in this study—leveraging classification performance as a proxy—enables an indirect yet insightful assessment of depth map quality. One noted limitation of this methodology, however, lies in its computational cost, which significantly exceeds that of more conventional error metrics. With extended time and computational resources, an extensive benchmarking of multiple depth estimation frameworks could be pursued under this accuracy-driven evaluation scheme to uncover deeper insights.

B. Advancing Learning on RGBD-Augmented Data

The present experimentation utilized relatively simple classification frameworks to emphasize the representational contributions of depth information. However, more sophisticated architectures remain unexplored within this context. A logical extension of this work would involve the deployment of high-performance deep neural networks trained on the constructed RGBD dataset. Evaluating such a dataset using cutting-edge models has the potential to yield even higher classification accuracies, potentially surpassing current benchmarks. Additionally, curating and releasing a wider array of RGBD-augmented datasets derived from widely used benchmarks would significantly contribute to community-driven advancements in multimodal learning.

C. Empirical Study: Estimated Depth vs. Ground-Truth Depth

An interesting comparative direction involves investigating the performance difference between models trained on RGBD data derived from estimated depth maps and those trained on datasets containing genuine depth measurements. Intriguingly, it is plausible that models utilizing estimated depth could demonstrate superior classification outcomes due to the abstract features inherently embedded by deep depth prediction models. These estimated maps, although synthetic, encapsulate high-level spatial cues not readily available through traditional RGB channels. A thorough empirical comparison between these two scenarios—estimated versus ground-truth depth—may offer valuable findings regarding the role of semantic abstraction in depth-informed classification tasks.

VI. CONCLUSION

This study successfully reconstructed a deep depth estimation network and utilized it to enhance a classic dataset by generating a novel RGBD extension of CIFAR-10. A new evaluation metric was conceptualized, wherein classification accuracy served as an indirect but meaningful indicator of depth prediction quality. The resulting RGBD dataset was subjected to a detailed analysis through both shallow and deep classification models, revealing that the added depth dimension consistently contributed valuable spatial information. Experimental outcomes highlighted that the inclusion of the depth modality improved classification performance across both fully connected and convolutional architectures. These results suggest that estimated depth features introduce beneficial representational enhancements, validating their integration into image understanding pipelines. Overall, the

findings endorse the continued exploration of depth-enriched datasets and transfer learning techniques in multimodal visual learning tasks.

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**EXPLORING THE BARRIERS IN PROMOTING
TRUE INCLUSION IN EDUCATION:
REMEDICATION THROUGH NATIONAL
POLICES AND LEGISLATIONS**



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EXPLORING THE BARRIERS IN PROMOTING TRUE INCLUSION IN EDUCATION: REMEDIATION THROUGH NATIONAL POLICIES AND LEGISLATIONS

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Abstract

The Constitution of India enshrines values like equality and social justice which promote the development of a humane and caring human society. The advancement of any society is dictated by its educational aims, goals and training system. All learners have the right to access quality education in order to pursue their dreams, reach their full potential and achieve to the fullest. Several national policies and legislations have been framed and enforced over the past few decades which have shape the inclusive practices. The present chapter focuses on the following major aims: a) explore the barriers faced in promoting true inclusion in education; b) the solutions provided by some key national legislations (RTE Act, 2009, RPwD Act, 2016 and the recent NEP, 2020) which have paved the way for removal of such barriers and c) some recommendations for the future improvement of Special Needs Education. The findings clearly indicate that inclusive education is a result of a rights based approach and the implementation of the measures mentioned in various legislations have led to the success of the same, however true inclusion is still a far cry from reality and the present study aims at showing the way forward to some extent.

Keywords: *Attitudinal Barriers, Inclusion, National Policies, Physical Barriers, Skill deficits, Social Barriers, Technology Barriers*

INTRODUCTION

Numerous reforms have been enacted in the sphere of inclusive education since independence and all these can be attributed to the policies and initiatives which have been taken by the Indian Government from time to time. The Kothari Commission had supported the need for non-discriminatory and quality education of children with special abilities. The

Policy of Integrated Education for Disabled Children (PIED) was launched in the year 1974. The National Policy of Education (NPE, 1986) and Programme of Action (POA, 1992) stressed the need for the educational system which was free, appropriate and offered equitable opportunities for all learners. The District Primary Education Program (DPEP, 1994-95) became a critical step in this direction through its emphasis on integrated and inclusive education. The Sarva Shiksha Abhiyan (SSA, 2000-2001) aimed to further promote the Universalization of Primary Education (UPE), Education for All (EFA) at the primary level. Rashtriya Madhyamik Shiksha Abhiyan (RMSA) was formulated to propagate inclusive education at the secondary level and finally both SSA and RMSA were integrated into the Samagra Shiksha Abhiyan.

Thus we see that over the past few years several revolutionary and path-breaking policies have been implemented including the Rehabilitation Council Act (RCI Act, 1992), the National Trust Act (NT Act, 1999), Persons with Disabilities Act (PwD Act, 1995), Right to Education Act (RTE, 2009) with the most recent policies being Rights of Persons with Disabilities Act (RPwD Act, 2016) and the National Education Policy (NEP, 2020).

Challenges faced toward promotion of “inclusion”: According to the literature reviewed some of the major challenges faced towards promotion of ‘inclusiveness’ in education at all levels including primary, secondary and higher education levels are stated as below:

- There is lack of proper enforcement of inclusive policies and legislations. This can be seen in the absence of regulatory measures over the assessment, training and evaluation approaches used in special schools (Singh, 2016; Pandey, 2020).
- Special educators lack the same status and pay scale as general educators, thereby facing discrimination and burnout (Singh, 2016; Chetwani, 2020; Rao & Shrivastava, 2020)
- Lack of clarity regarding the term ‘inclusion’ and insufficient address of the pertinent question faced by most guardians of learners with Special Educational Needs (SENs) “What after me?” The National Trust Act for the first time brought out the provision of guardianship for Divyangjan (Intellectual Disability, Multiple Disability, Autism and Cerebral Palsy). However, this area needs to be addressed further as a thrust area (Rao & Shrivastava, 2020).

- Less focus felt on issues related to social security and additional benefits for Persons with Disabilities (PwDs).

This chapter looks at the unique measures and clauses laid down under each of the selected legislation and tries to explore how these policies address the challenges discussed. Critical analysis of the reviewed literature and the targeted policies was done to identify the solutions offered by these national legislations. These solutions are further grouped into several headings such as provisions for: a) inclusive education b) social inclusion, c) technological inclusion, d) physical inclusion, e) effective implementation among other critical aspects. Efforts have also been made to identify roadblocks which hinder successful implementation of inclusion and make it far from reality. These limitations have been discussed to aid their remediation through effective and lawful measures in the near future.

Right to Free and Compulsory Education (RTE), 2009

Salient features: It is a landmark law that mandates the provision of free and compulsory education for all children in the age group of 6-14 years.

Special Provisions under RTE, 2009 to remediate the numerous challenges and issues faced:

Provisions for efficient governance: it lays down clear policies for the governments to endeavor to integrate children with disabilities into mainstream schools by mapping and also take steps to ensure enrolment, retention and completion of elementary schooling.

Provisions for inclusive education: schools should be set up within 1 km distance in the neighborhood for primary schools and for schools 6-8, within 3 kms.

Provisions for accessibility: the schools should ensure barrier free access to all children and facility of appropriate transport for reaching the schools

Provisions for maintenance of standards: the RTE act has laid down minimum Pupil Teacher Ratio (PTR) as 30:1 and the commitment to have trained teachers. Every school should have basic infrastructural facilities like playgrounds, libraries, toilets, drinking water facilities.

Provisions laid down under the 2012 amendment of the RTE act: It mandates that parents of Children with Disabilities (CwDs) have to be included in the school management committees (SMCs), as such collaborations can positively impact the planning and

development of inclusive approaches in the schools. Thus the act has made provisions for promoting positive interaction between parents-professionals and school management which is integral to the success of any inclusive program and its implementation. As per the amendment of the Act, CwDs are included under the 25% Economically Weaker Section (EWS) category thereby giving them the opportunity to avail facilities reserved for children belonging to marginalized section of the society. In addition to this, the Act further added a clause which permitted children with severe and profound disabilities to opt for home based education (1).

Rights of Persons with Disabilities Act (RPwD), 2016

According to (Rani, 2018) the RPwD Act, 2016 and inclusiveness are very intrinsically intertwined. Some salient features of the Act:

- For the first time 21 types of disabilities have been considered (as shown in table-1). Disability has been defined keeping it evolving nature and benchmark disabilities have been defined ‘as those having at least 40% or above disabilities’ and are certified by medical professionals.
- Additional benefits for those with benchmark disabilities in the form of social security measures such as reservations and other facilities.
- Free and compulsory education to all children with benchmark disabilities.
- Ensuring accessibility in public spaces and buildings.
- More power given to Chief Commissioner, State Commissioner of PwDs along with effective grievance redressal measures through setting up of designated special courts.
- Creation of National State Fund and enforcing heavy penalties for offences committed against Divyangjan.

Table 1. Various types of disability considered under the RPwD Act (2016)

S. No.	Type of Disability	Conditions included
1	Physical Disability A. Locomotor Disability	a) Leprosy cured person b) Cerebral Palsy c) Dwarfism d) Muscular Dystrophy e) Acid Attack Victims

	B. Visual Impairment	a) Blindness b) Low Vision
	C. Hearing Impairment	a) Deaf b) Hard of hearing
	D. Speech and Language Disability	Aphasia
2	Intellectual Disability	a) Specific Learning Disability b) Autism Spectrum Disorder
3	Mental Behavior	Mental Illness
4	Disability due to: a. Chronic Neurological Conditions b. Blood Disorder	i) Multiple Sclerosis ii) Parkinson's Disease a) Hemophilia b) Thalassemia c) Sickle Cell Disease
5	Multiple Disabilities	Deaf-blindness
6.	Any other	Provision to add more disabilities

(Adapted from RPwD Act, p. 33-35)

Special Provisions under RPwD Act, 2016 to remediate the numerous challenges and issues:

Provisions for inclusive education: The Act follows the principles of inherent dignity, individual autonomy, non-discrimination, acceptance, full and equal participation of persons with disabilities as laid down by the United Nation Convention on the Rights of Persons with Disabilities (UNCRPD, 2016). It stresses on the provision of reasonable accommodations for all in the form of appropriate and necessary modifications. The Act proposes early identification and assessment of learning disabilities for provision of appropriate facilities along with appropriate modes of communication and instruction for those with sensory disabilities.

Provisions for Physical inclusion: Chapter III on education specially mentions on the need for making public buildings accessible. Barrier free environment needs to be provided in all polling sites (chapter II).

Provisions for social inclusion: The Act entitles special rights to PwDs such as right to equality and dignity. It mandates the provision of informed consent through accessible modes and forbids any form of ill-treatment or abuse. The Act has provisions for promoting accessibility in voting (chapter II). Exclusive skill training to be promoted for such persons in accordance with the Act (chapter-IV), provisions of safety and security, aids and appliances

guaranteed for PwDs. Insurance schemes to be made available for employees with disability (chapter-V).

Provisions for teacher training: training of teachers to be encouraged in the areas of Braille and Indian Sign Language (ISL). Such trained teachers to be employed along with those trained in teaching children with Intellectual Disability. Scholarships to be provided to all children with benchmark disabilities, resource rooms to be set up which will support the educators of CwDs (chapter-III).

Special provisions for benchmark disabilities:

In chapter VI of the Act, there are special mandates for those having benchmark disabilities such as: free and compulsory education in neighborhood schools between 6-18 years of age, reservations in the institutes of higher education, 4% reservations for jobs in government establishments, including Autism Spectrum Disorder (ASD), Specific Learning Disability (SLD) and Mental Illness (MI). Special employment exchanges to be setup. The chapter VII further mandates special provisions for those with high support needs.

Provisions Technology inclusion: Chapter VIII of the Act talks about provision for access to information and also the accessibility standards that need to be set up by appropriate governments for ease of access.

Provisions for maintenance of standards: Chapter VIII mandates social audits of all schemes and provisions concerning PwDs to ensure proper regulation and avoid any misuse.

National Education Policy (NEP), 2020

It defines inclusive education as a ‘system of education wherein students with and without disabilities learn together and the system of teaching and learning is suitably adapted to meet the learning needs of different types of students with disabilities’.

The NEP 2020 aims to create a knowledge economy (Rai, 2020) and the creation of the national educational technology forum to advance digital and e-content, however a proper framework and roadmap is needed to fully utilize such resources for PwDs.

According to (2), some path breaking initiatives taken by the policy is the provision of constituting Special Education Zones to provide targeted approach.

Special Provisions under NEP, 2020 to remediate the numerous challenges and issues

Special Provisions NEP, 2020 to remediate the numerous challenges and issues faced:

Provisions for physical inclusion: The Act mandates the provision of adequate resources to schools for promoting integration through certain steps such as establishment of resource centers, providing barrier free access to all children, infrastructural resources like barrier free classrooms, playgrounds, drinking water and toilet facilities for the learners (clause 6.11. p.26-27). The RPwD Act, 2016 also stresses on accessibility to appropriate barrier free environments as mandated under the Accessible India Campaign.

Provisions for teacher training: The Act mentions about recruitment of special educators with cross-disability training especially for children with severe or multiple disabilities (clause 6.11). Resource centers are used to support such educators the teachers (clause 6.12). The Act further mentions about provision of continuous support to children with SLD after proper identification, assessment by the trainers (clause 6.13). Teacher trainees will be given specialized training to train, handle and manage such learners with LD (clause 6.14). The requirement of additional special educators for specific subjects especially learners in the middle and secondary school levels will be fulfilled (clause 5.1). In order to ensure skill training and capacity building among pre and in-service educators training programs in the form of certificate courses have been proposed both as part time and full time courses. The Act also aims at achieving greater synergy between the course curriculum of National Council for Teacher Education (NCTE) and the RCI. It further mandates that teachers must be sensitized towards needs of learners with disability including those with Learning Disability (clause 5.9).

Provisions for technology Inclusion: Children with Special Educational Needs (CwSEN) have unique needs. They need assistive devices and appropriate technology-based tools for teaching and learning process (such as textbooks in accessible formats, use of Alternative and Augmentative Communication devices, magnifiers etc.). Such assistive devices will be applicable across subjects and all school activities (clause 6.11). Focus will be laid on usage, training and integration of sign language learning across several subjects.

Provisions for maintenance of standards: The Act clearly mentions that children with benchmark disabilities shall have the choice for opting regular or special schooling. For children with severe and profound disabilities Home Based Training (HBT) will be available, and they will be treated at par with any other learner (clause 6.12.). Home based educational

audits will be conducted from time to time to test the efficacy of this model; appropriate guidelines will be developed in line with RPwD Act 2016 (clause 8.5). The act also mentions the need for setting up of a quality accreditation system for all stages of education such as a body called the State School Standards Authority (SSSA).

Provisions for guidance and training for parents: The Act has provisions to orient, guide and train parents/care givers of CwDs through technology driven solutions and activities (clause 6.12).

Provisions for curricular flexibility: usage of appropriate technology with flexible curricula. The guidelines for assessment and appropriate tools will be suggested by the new National Assessment Centre- Performance Assessment, Review, and Analysis of Knowledge for Holistic Development (PARAKH) in order to ensure equitable access and opportunities for all students with learning disabilities (clause 6.13). The Act further advocates the need for individualized education, peer tutoring, open schooling and suitable technological interventions to ensure equitable access for learners with SEN (clause 6.5). The Act has also made provisions to improve attendance and retention by connecting with parents, counselors etc.

Provisions for inclusive education: standardization of Indian Sign Language (ISL). the act further aims at equalization of the educational opportunities for the Socio-economically Disadvantaged Groups (SEDGs) including CwDs by bridging the gaps across access, participation and learning outcomes with special focus on secondary education. Further the policy recognized the need to create enabling mechanism for CwSEN to help them gain equitable opportunities.


Early Childhood Care and Education (ECCE) was also to be given key importance and the curriculum for ECCE would include guidelines for parents and teachers for age groups up to three years and a framework for learners 3-8 (Chetwani, 2020). Highest priority has been accorded to the CwDs and their participation in ECCE and educational system. The policy is in complete consonance with the RPwD Act (2016) and has built upon its recommendations.

A comparative study between the provisions of the three targeted legislations is shown as follows:

Table 2. Comparisons between the provisions of the three targeted legislations

Provisions	RTE Act, 2009	RPwD act, 2016	NEP 2020
Provisions for	Schools should be set up	❖ Follows the	🇮🇳 Recruitment of

inclusive education:	<p>within:</p> <ul style="list-style-type: none"> • 1 km distance in the neighborhood (primary level). • Within 3 kms (for classes 6th-8th). • CwDs included under 25% reservation. • Policies for governments to integrate CwDs into mainstream schools by mapping. • Ensure enrolment and retention of learners. 	<p>principles laid down by UNCRPD 2016.</p> <ul style="list-style-type: none"> ❖ Reasonable accommodations for all. ❖ Need for early identification. 	<p>special educators with cross-disability training.</p> <ul style="list-style-type: none"> + Continuous support to children with SLD. + Certificate courses for pre and in-service teachers. + Availability of appropriate technology-based tools. + Training and integration of sign language learning across several subjects. + Equalization of the educational opportunities for the SEDGs. + Need to create enabling mechanism for gaining equitable opportunities. + Need for ECCE.
Provisions for physical inclusion and accessibility:	<p>Schools should ensure:</p> <ul style="list-style-type: none"> • barrier free access • facility of appropriate transport 	<ul style="list-style-type: none"> ❖ Need for making public buildings accessible. ❖ Barrier free environment provided in all polling sites. 	<ul style="list-style-type: none"> + Provision of adequate resources + Establishment of resource centers. + providing barrier free access to all children, + Barrier free environments.
Provisions for maintenance of standards:	<ul style="list-style-type: none"> • Minimum Pupil Teacher Ratio (PTR) = 30:1 and the commitment to have trained teachers. • Every school should have basic infrastructural facilities. 	<ul style="list-style-type: none"> ❖ Social audits of all schemes and provisions concerning PwDs . 	<ul style="list-style-type: none"> + Home Based Training (HBT) will treated at par with any other learner + Home based educational audits + Setting up of State School Standards Authority (SSSA). + Usage of appropriate

			technology with flexible curricula.  The guidelines for assessment will be suggested by PARAKH
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Discussion

Despite several path breaking legislations and policies already in place, the reviewed literature clearly points out that there are several challenges and problems in the true implementation of inclusion and thereby making inclusion a reality on paper than practice. Some of these limitations are discussed below:

Despite provisions laid down by RPwD Act (2016) yet we see that there is still lack of skill training among special educators and stakeholders which affect the achievement of desired objectives (Rani, 2020; Chetwani. 2020). A lack of proper social and societal awareness regarding Divyangjan and their rights, abilities and capacity their abilities adversely impact the adoption of inclusive attitude and practices in the society (Singh, 2016). Despite reservation quota available for persons with disabilities there is need for more studies on finding out the effectiveness of the RPwD Act 2016. The RTE Act defines disability in line with the PwD Act 1995. It should define inclusive education with the current disability rights framework. Several parents whose children attended special schools initially got the student admitted to ordinary neighborhood school however when the school's discovered that the child had disability the child referred to a special school. Many educators responded that their school and organization often lacks facilities needed for special needs children. Further parents have limited choices while approaching schools despite having three models of schools that is special schools, general schools and home based training. The NPE 2020 on the other hand is aimed at transforming the Indian educational system for the better, however faces some limitations.

Hence we see that in spite of several positive measures and provisions implemented through evolution in the policies and legislations in the country, the education of CwSEN remain excluded and narrow in scope due to narrow interpretation and implementation of several legislations and more dependence on SSA for improving the education and training of the target group.

According to Alkazi (n.d.), the narrow interpretation can be understood in terms of:

- Narrow interpretation of barrier free environments to provision of only ramps and rails.
- Narrow interpretation of curriculum provisions limited to disability specific adaptations and modifications of the curriculum and teaching methods.
- Narrow interpretation of Teaching Learning Materials (TLM) such as making only Braille and large print available to candidates with SEN.
- Narrowed interpretation of inclusive education personnel to availability of trained special educators with little or no fit to general education.

Key recommendations:

- There is a strong need to avoid all narrow forms of interpretation of legislations and policies supporting and promoting inclusion.
- We need to work towards promotion of accessibility in information, transportation and communication for CwDs through special focus on ISL, accessible transport mechanisms and use of alternative technologies for teaching and learning.
- Home based training needs to be considered at par with the other models of schooling available for CwDs and enrolling full time professionals for such modes.

Conclusion

From the present chapter, it is imperative that there is a strongly felt need for greater flexibility in the educational system to effectively include children with SEN. There is need for greater commitment to provide barrier free transportation to students with Special needs and make basic facilities like drinking water, toilet and mid-day meals accessible such children. There has to be greater focus on curriculum which has to be made more inclusive, pedagogies should become more diverse and applicable to CwSEnS and greater focus needs to be made towards provision of appropriate TLM to such children. Home Based Training require greater support in form of trained and fulltime personnel, specially catering to the needs of the target group. We all have to ensure that CwDs derive benefit from the numerous legislations and policies and such measures pave the way towards making true inclusion a reality in the near future.

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**India is positioning itself amid shifting Geopolitical
Alliances and Trade Agreements- A Review**



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India is positioning itself amid shifting Geopolitical Alliances and Trade Agreements- A Review

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Abstract

Asia's fast growing economic power, India, is maneuvering through a very dynamic global environment characterized by the international relations in play and the negotiation of free trade agreements. When it comes to Russia or other South Asia neighbour's or Russia, the country maintains such ties, but meanwhile is focusing on forging strategic partnerships with the main powers such as the U.S., Japan or Australia to boost its global influence. Due to the fact that their security and economic interests are concerned by such regional and global forums as Indo-Pacific region, the Shanghai Cooperation Organization (SCO), and BRICS, India is adapting its foreign policy, so it is becoming oneself of a key player in these forums. At the same time, India is actively involved in multilateral trading agreements to build up its economic contacts, especially with the growing trend of protectionism and modification of global trade regimes. India's plan of diversifying its economic relations is reflected in the Comprehensive Economic Partnership Agreement (CEPA) with the United Arab Emirates (UAE) and discussions on joining the Regional Comprehensive Economic Partnership (RCEP). Besides that, India is faring towards being a main player in the 21st century's global circulation ambitions to become a part of the actual global supply chain by investing considerably in technology and infrastructure. In India, though, despite the American dollars and the combination of the Singapore and the Clipper and the SNC, its diplomatic stance is still underpinned by the policy of 'Strategic Autonomy' and this means that India's sovereignty is safe. India is able to use its democratic values, economic growth potential and strategic partnerships to place itself as a central force of reshaping global order in the 21st century.

Keywords:- *Geopolitics, Trade Agreements, Strategic Alliances, India's Foreign Policy, Economic Partnerships*

Introduction

Given the politicoeconomic volatility in the global system, India is geared up to strategically play its role as one of the fastest growing economies in the world. With the latest shift of power from developed to developing countries, the current global order is increasingly described as multipolar, manifested in the rise of countries from East, such as India, and bringing forward new challenges and opportunities. Just as traditional alliances in the West are evolving at the same time, India seeks a wider range of global partnerships to boost its security, economic growth and political clout. India's coggy foreign policy is founded on being motivated by what it terms as Strategic Autonomy, i.e., India is allowed to have the liberty to engage with various global players in a politicized fashion. With a rise in protectionism, trade wars and regional tensions happening across the world, India is taking steps on regional and multilateral trade agreements for its protection (Bajpai et.al 2019). However, the key partnerships in which India is involved – with the United States and Japan, as well as with Russia – are being forged today as never before, as with so many things in the world over global supply chains are undergoing large changes. India's role as central player for promoting security, economic stability and cooperation in Indo Pacific region is growing. In addition, the country is developing in various areas such as technology, manufacturing, and infrastructure in order to take the place as an essential part of the world's value chains. So, India is using its democratic values, strong economy, and strategic location to even more influence the world and claim its seat on a world stage that will help set the shape for the future of global geopolitics and trade (Chatterjee et.al 2018).

Research Aim

It seeks to understand how India is strategically positioning itself in the changing geopolitical alliances and the changing global trade agreements.

Objectives

- To examine India's approach to strengthening strategic alliances with key global powers.
- To assess India's participation in regional and multilateral trade agreements and its economic impact.
- To explore the role of India's "Strategic Autonomy" in shaping its foreign policy.

- To evaluate India's investment in infrastructure and technology to enhance its global positioning.

Literature Review

Exploring the role of India's "Strategic Autonomy" in shaping its foreign policy.

India's idea of 'Strategic Autonomy' has perhaps been pivotal in molding India's foreign policy to ensure that the country remains flexible, and essentially autonomous in its stance before changing Global Dynamics. This strategy rests on India's desire to assert India's sovereignty and freedom of action as India interacts with major global powers and the larger regional players. While the concept was introduced during the Cold War, the concept has evolved, but the basic premise regarding that India will be involved with different countries and alliances as per its national interests without any dependence to any superpower or bloc has not changed. India, however, historically has always been guided by a non alignment movement which prevented the country from aligning itself with any of the super powers associated with the cold war. In this context strategic autonomy referred to India's independence while making decisions in global affairs (Mohan et.al 2020). It is true that India chose the non aligned approach but the neutrality in it was not solely for India. It was defined by an active diplomatic stance which allowed India to maintain good relations with both the Soviet Union as well as with the United States and use both sides when it was required to achieve its development goals. The concept of strategic autonomy that helped India remain poised in terms of its national security interests as it entered the 21st century, was further altered to respond to the challenges of an increasingly interlinked and multipolar world. Kanti Bajpai (2006) believes that India's foreign policy approach has rested in a pragmatic flexibility that has availed India the opportunity to advance its interests without commitment to one alliance (Saran et.al 2021). This has been particularly helpful in the context of India's major global partners — the United States and China — it said. Both India and Pakistan, though they had differences, have also tried to keep their relations with both powers in a fine balance as the support from both powers were considered essential for the economic and security worries of the country. Moreover, strategic autonomy gives the ability to the country to forge closer ties with regional powers like Japan, Australia, and all those in Southeast Asia, and to engage with multilateral bodies like the United Nations, BRICS, and the Shanghai Cooperation Organization (SCO). For example, India has made use of strategic autonomy to achieve national security while contributing towards regional stability by pursuing participation of India in the Quad (Quadrilateral Security

Dialogue) along with the United States, Japan and Australia. Also, Mohan (2015) ascribes that the Quad does not just highlight the need to counter China's influence, but also the need of India to exercise its independent agency in a region which is fast becoming a contested one. The idea of strategic autonomy is nothing but economic or security considerations. India's ability to undertake negotiations and secure favourable terms in multilateral trade agreements including the Regional Comprehensive Economic partnership (RCEP) and bilateral agreements with the United States and the European Union, represents its independence in terms of its economy. India is keen to stay off the dependency on a single country or a trade bloc as policymakers like Shyam Saran (2017) write. Maintaining the strategic autonomy, India can find its way through the global trade agreements by keeping in mind its long term economic goals without being forced into making unsustainable commitments (Biswas et.al 2019). India's thirst for strategic autonomy also affects India's domestic politics, as well as its national identity. Being a democracy with diversified population, growing economy, India's foreign policy is very sensitive and as a result merges between national development and international interference. According to scholars like C. Raja Mohan (2020), India's policy of strategic autonomy gives India the freedom to safeguard its values like democracy and non interferences while ensuring there is no shielding of its sovereignty by external powers. At any rate, India's strategic autonomy has remained a bedrock of the country's foreign policy. It provides India the opportunity to interact with a number of different powers at the global level and to play a role in a fast changing world at the global level while also advancing its national interests in a global context. India's ability to retain this flexibility and increase its global standing will become fundamentals in its foreign policy in this new balance of power (Brewster et.al 2019).

Examining India's approach to strengthening strategic alliances with key global powers.

With the changing geopolitical dynamics, India has increasingly recognized that strategic alliance with the global powers forms a key component of its foreign policy. India's diplomatic posture has been molded in such a way that it is making full efforts to properly perform its role in the global affair while looking after its national interest. With a growing influence of United States, China, Russia and the European Union, India's approach to developing of strategic alliances has largely been determined by its specific geopolitical, economic and security concerns among them. Since the 1990s, the United States and India have developed a remarkable relationship. Difference between Cold War era India and the U.S. brought the relations between the two to a halt, but the end of the Cold War and India's economic liberalisation in the 1990s have laid the foundation for a greater cooperation. Sumit Ganguly

(2005) also cites that the U.S. – India relationship has entered into a new phase of strategic engagement after the 2005 civil nuclear agreement (Gupta et.al 2020). This also marked a major change in India's relationship with the U.S. and an inevitable rise of India in the big league. Since then, the bilateral relationship has been built on regular dialogues on defence, trade, technology and regional security, particularly in the Indo Pacific region. India's association with the United States takes shape because it shares democratic values with America and because it worries over Beijing's rise and local security issues. India's deepening partnership with Japan is equally important (Rajagopalan et.al 2020). The relationship with Japan has been based on mutual understanding of economic cooperation as well political, strategic and technological interests especially in the Indo-Pacific region. Ryo Sahashi (2014) among others mentions that as a leading economic power and also as being an expert in technology, Japan is an important partner for India in regard to infrastructure development, clean energy and so on. Additionally, Japan's strategic interests and its counter China interest lines up with India's. High level visit and agreement like the Japan India Comprehensive Economic Partnership Agreement (CEPA) which aims at strengthening the trade and investment flow between both countries has paved the way for the partnership. The relations have been strengthened by the maritime security and freedom of a navigation in the South China Sea where India and Japan also hold concerns and collaborating through the quad, an umbrella term for the U.S. and Australia. However, despite the change of dynamics, India's strategic alliances with Russia continues to be an important part of India's relationship with Russia. India also has strong defence cooperation and energy ties with Russia which has sustained historical partnership with India. Arvind Gupta (2017) says that Russia has been an important source of defence equipment for India and the two countries have always come together in the multilateral forums like the United Nations and the Shanghai Cooperation Organization (SCO). India's rise is challenging but Russia remains an important partner, in the defence and especially the energy sectors. However, India has also balanced its relationship between Russia and the United States, asserting its strategic autonomy (Mahapatra et.al 2020). The defence trade between the two countries is a part of this relationship that is timeless, and the defence trade takes the shape of the purchase of the S-400 missile defines system. India's approach to strengthening strategic alliances is also written in its partnership with Australia in view of the country's growing relationship with that country. The two countries share the same values on democracy, rule of law and a free and open Indo-Pacific. Scholars such as David Brewster (2017) state that Australia has been an important partner for India in checking China's influence in the region. The two countries further enhance their bilateral relationship through areas such as defence,

counterterrorism, and regional security (Bhardwaj et.al 2021). Within the Quad both have expanded the strategic dialogue and their collaboration has got strengthened in light of mutual concerns over China's assertiveness in the Indo Pacific. In addition, the active participation of India in multilateral organisations like BRICS (Brazil, Russia, India, China and South Africa) and G20 help India to exercise an influence on global governance and promote its economic interests. India's pragmatic approach to safeguarding its national security, national economic prosperity, and the global sway expresses itself in its ongoing focus on development of these alliances while maintaining its strategic autonomy in the global order as it evolves. To conclude, foreign policy of India has come to rest on its strategic alliances with the key global powers. The engagement of India with U.S., Japan, Russia, and Australia does more than secure India's security interests; India is demonstrating itself to be a significant player in the unfolding geopolitical realignment. These partnerships ensure that India progresses on its own measures in the face of ever-shifting realities on the global stage (Krishnan et.al 2020).

Methodology

In this study, India's geopolitical positioning/offering within marginalised geopolitical alliances and trade agreements would be evaluated using quantitative research methodology. Sources of primary data will be secondary databases such as trade statistics, geopolitical reports, International Agreements and Economic Indicators. Trade volumes, foreign direct investment (FDI), bilateral trade agreements, participation in defence collaborations are some of the focus data points. For data analysis, the spss software will be used. The trends in India's trade agreements, foreign investments and participation in geopolitical alliance(s) over a period are to be summarized via descriptive statistics. To explore the relationship between India's participation in international trade agreements and India's economic performance (e.g., GDP growth, export import ratios, FDI inflows) regression analysis will be done. The long term impact of shifting alliances on India's economic journey will also be tested using a time series analysis. The strength of relationship between India's geopolitical strategies and trade outcomes will be analysed by the correlation analysis. The aim of the results will be to provide statistical evidence of how India's economic growth and position in the world are dependent on its geopolitical positioning and participation in Global geopolitics and trade agreements. This will present an incontestable and data-based view of India's strategic moves in the international arena.

Analysis

Demographic analysis

Age

What is your age?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-25 years	28	28.0	28.0	28.0
	26-30 years	37	37.0	37.0	65.0
	31-35 years	14	14.0	14.0	79.0
	36 year and above	21	21.0	21.0	100.0
	Total	100	100.0	100.0	

Table 1: Age distribution

(Source: SPSS)

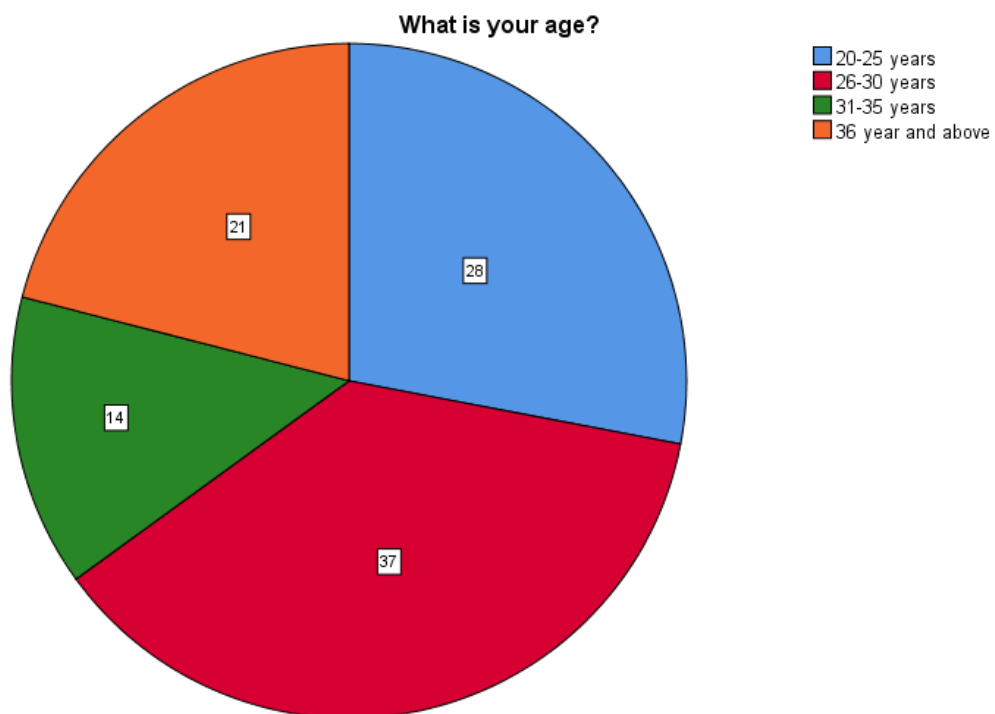


Figure 3: Age distribution

(Source: SPSS)

The table and the pie chart of distribution give a proper understanding of the differences in the participation of the people with different age groups from 20 to 36 years and above. The table gives the understanding of the highest participated people in the survey which belongs from 26 years to 30 years with the frequency 37 and a cumulative percentage of 65%. The lowest people who participated in the survey are within the age group 31 to 35 years and the cumulative percentage is 79%.

Gender

What is your gender?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	30	30.0	30.0	30.0
	Male	20	20.0	20.0	50.0
	Others	14	14.0	14.0	64.0
	Prefer not to say	36	36.0	36.0	100.0
	Total	100	100.0	100.0	

Table 2: Gender distribution

(Source: SPSS)

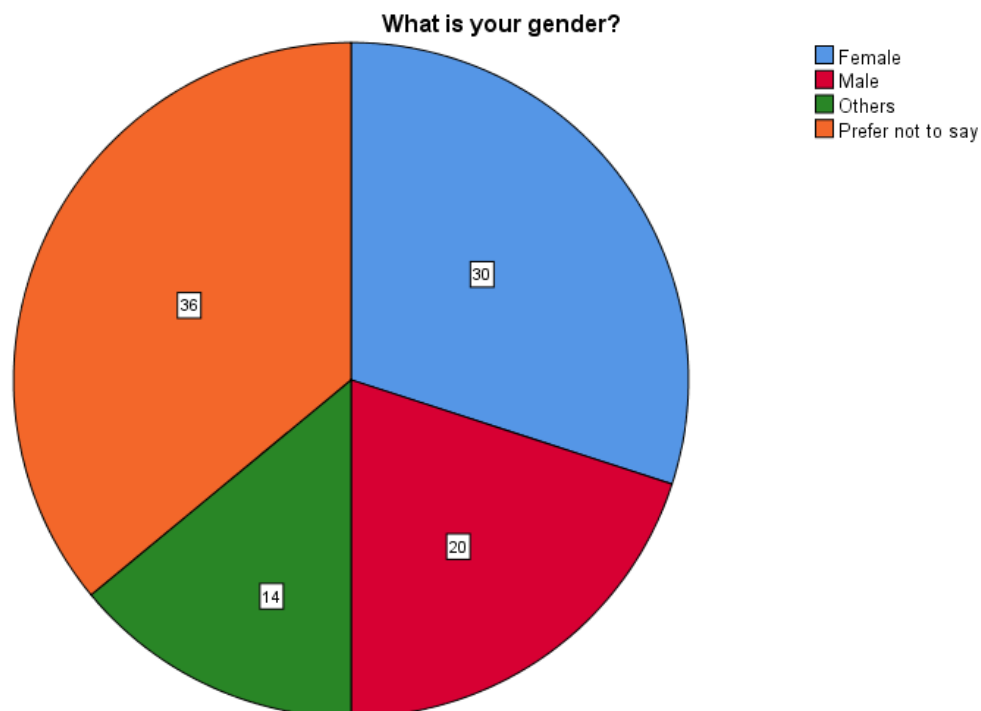


Figure 4: Gender distribution

(Source: SPSS)

The percentage of people of other genders is the highest that is 64% with a frequency of 14 which means the highest enthusiasm among these people about the survey related to the deposition of India in the geopolitical alliances and trade agreements. From the above pie chart, it can be clearly said that the people who do not want to say that gender is the highest participated with 36 frequencies and allocated the most of the section in the pie chart.

Qualification

What is your education qualification?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	B.Com	30	30.0	30.0	30.0
	B.Sc	34	34.0	34.0	64.0
	Graduate	15	15.0	15.0	79.0
	M.Com	21	21.0	21.0	100.0
	Total	100	100.0	100.0	

Table 3: Qualification distribution

(Source: SPSS)

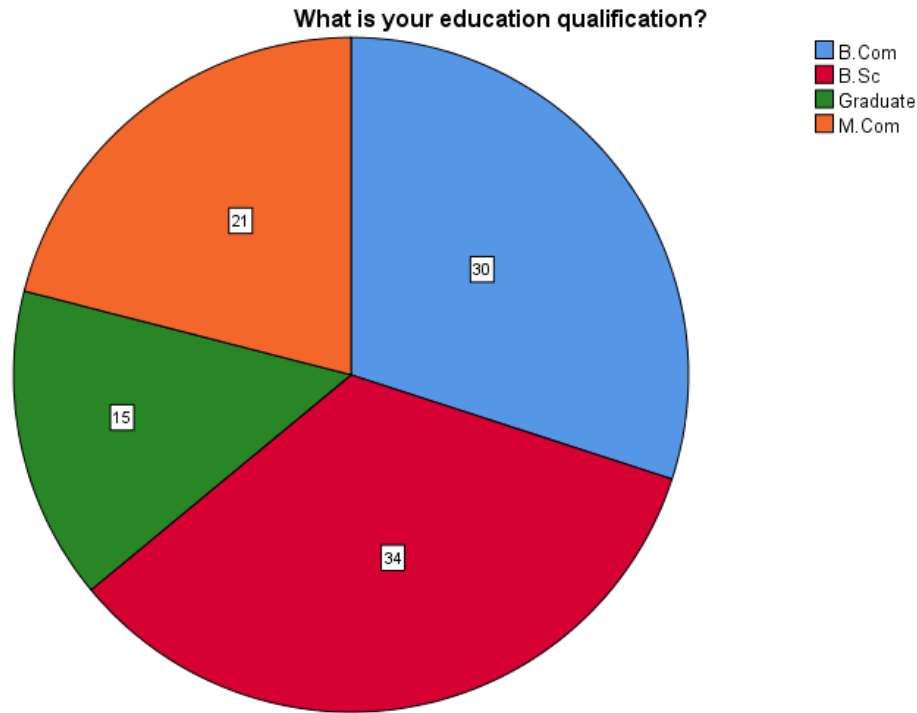


Figure 5: Qualification distribution

(Source: SPSS)

From the table of qualification distribution, the highest frequency of people who participated in the survey can be determined. The highest frequency is for the people who have completed their BSc degree is 34 and the cumulative person is 64%. The people who completed their graduation are at the lowest frequency with 15 and the cumulative percentage with 79%. Therefore it can be said that the people with a BSc degree are the most interested in knowing the political alliance and trade agreement effect on the positioning of India.

Descriptive analysis

Descriptive Statistics									
	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic	Skewness		Kurtosis	
						Statistic	Std. Error	Statistic	Std. Error
DV_geopolitical alliances	100	1	5	3.33	1.311	-.609	.241	-1.028	.478
IV1.1_trade 4ments	100	2	5	3.16	1.324	.553	.241	-1.507	.478
IV2.2_multilateral forums	100	1	4	3.10	1.267	-.799	.241	-1.206	.478
IV2.3_FTA strategy	100	2	5	3.61	.973	-.082	.241	-.969	.478
IV3.1_strategic autonomy	100	1	5	3.23	1.536	-.209	.241	-1.421	.478
IV3.2_geopolitical dynamics	100	3	5	3.87	.906	.262	.241	-1.748	.478
Valid N (listwise)	100								

Figure 6: Descriptive analysis

(Source: SPSS)

The table of descriptive analysis of the current study is one of the most important analytical factors by which the main statistics the standard deviation statistics can be defined. The minimum statistical value is one and the maximum is value which is for the political dynamics that indicates the impact on geo-political dynamics is the highest among all other independent variables on the geo-political alliance in India. The value of mean statistics for the multilateral forums is 3.10 which is the lowest value of mini statistics that connected with the geo-political alliance in India.

Factor analysis

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.289
Bartlett's Test of Sphericity	Approx. Chi-Square	452.431
	df	10
	Sig.	.000

Figure 7: Factor analysis

(Source: SPSS)

The table of factor analysis gives a proper analytical value for the study to evaluate the impact of different Geo political alliances and factors on the growth and development of trade agreements and positioning of India's geo-politics. The value of an approximate choice girl is 452.431 this is a high value that indicates the Orelationship between the Geo political positioning and alliance in India. The value for sampling adequacy for the latest taste is 0.289 this is less than 0.6 shows the list importance for the independence on the dependent variables of the study.

Reliability test

Reliability Statistics

Cronbach's Alpha ^a	N of Items
-.004	6

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

From the reliability test, the values of Cronbach's alpha can be developed which includes 6 items from the study. The negative value of this Alpha is minus 0.004 showing the lack of effectiveness of the independent variables with the dependent variables of the study. From the negative value calculating the impact of IVs on the DV gives an overall understanding of the low impact of the Geo-political facilities and FTA strategies for the Geo political alliances in India.

Hypotheses Testing

Hypothesis 1: The geopolitical alliance's and multilateral forums are connected to each other

Model Summary ^b										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	Change Statistics			Sig. F Change	Durbin-Watson
						F Change	df1	df2		
1	.367 ^a	.134	.126	1.226	.134	15.221	1	98	.000	2.537

a. Predictors: (Constant), IV2.2_multilateral forums

b. Dependent Variable: DV_geopolitical alliances

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.868	1	22.868	15.221	.000 ^b
	Residual	147.242	98	1.502		
	Total	170.110	99			

a. Dependent Variable: DV_geopolitical alliances

b. Predictors: (Constant), IV2.2_multilateral forums

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.506	.325		13.850	.000
	IV2.2_multilateral forums	-.379	.097	-.367	-3.901	.000

a. Dependent Variable: DV_geopolitical alliances

The regression and hypothesis testing table is one of the best examples for understanding the proper effectiveness of independent variables on the dependent variable of the study. This table of hypothesis testing gives a result by including the test for model summary and over and coefficient that helps to understand the exact importance of the amid shifting and the geopolitical alliances. The sum of a square for the residual value for the dependent variable and the independent variable IV 2.2 that is multilateral forums is 147.242. this high residual value showcases the effectiveness and importance of the implementation of different multilateral forums on the alliances.

Hypothesis 2: There is a relationship between the geopolitical alliance's and geopolitical dynamics

Model Summary ^b										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	Change Statistics			Sig. F Change	Durbin-Watson
1	.496 ^a	.246	.238	1.144	.246	31.913	1	98	.000	2.355

a. Predictors: (Constant), IV3.2_geopolitical dynamics

b. Dependent Variable: DV_geopolitical alliances

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	41.787	1	41.787	31.913	.000 ^b
	Residual	128.323	98	1.309		
	Total	170.110	99			

a. Dependent Variable: DV_geopolitical alliances

b. Predictors: (Constant), IV3.2_geopolitical dynamics

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.556	.504		1.102	.273
	IV3.2_geopolitical dynamics	.717	.127	.496	5.649	.000

a. Dependent Variable: DV_geopolitical alliances

Figure 10: Hypothesis testing 2

(Source: SPSS)

The second table of equation analysis becomes one of the important values of standard Era estimation with adjusted R squares which helps to get the proper justification of your political dynamics on the growth of the geo-political alliances in India. Therefore, the value for recreation that can be obtained from the hypothesis table is 1.787 which shows that the proper implementation of the political factors can improve the dynamics which also leads to the betterment of the political alliances.

Discussion

It is not surprising that India's foreign policy, epitomized by the principle of 'Strategic Autonomy,' the country's options of positioning itself in shifting geopolitical alliances and evolving trade agreements. Strategically India has tied up with major powers like US, Japan, Russia, Australia and still retains its sovereign status in decision making. This flexibility has allowed India to protect its sovereignty and to be reactive to the ever growing global challenges especially now with the growing strength of the China in the Indo Pacific region. Participation of the country within multilateral forums including the Quad, BRICS and UN that are ensures the development of relations with both developed and emerging economies as well as ensuring

the interest of global security. For instance, India's close contacts with the US testify to its common concern with the region's security, especially pressured by China's boldness. A major turning point in the bilateral relations occurred with the 2005 U.S. – India Civil Nuclear Agreement, symbolising the deepening of the relations, and they are expanding in different fields, such as defence, technology and trade. As is the case with India and Japan so does the partnership between the two countries based on their common concerns of regional stability and security, which is further affected by China's military expansion (Fernandes et.al 2021). Such alliances, however, help India to increase its diplomatic clout and continue on its way to winning the status of the main player in global governance. Though India's engagement with Russia is important, in particular in defence, it is paramount. India has successfully managed to keep up its frosty relationship with Russia even as it strengthened its ties with the West. Additionally, India's participation in regional trade agreements, such as the Comprehensive Economic Partnership Agreement (CEPA) with the UAE, showcases the country's commitment to economic growth through diversification of trade partners. Overall, the stability of strategic alliances coupled with strategic autonomy for India allows it to steer the intricacies of the multipolar world and be sovereign and of influence on the global scene in an increasingly connected and competitive global arena.

Conclusion

India's foreign policy, particularly in terms of position of such India in the context of shifting geopolitical alliances and emerging trade agreements, has been extremely adaptive and pragmatic. Rather, India's systematic commitment to 'Strategic Autonomy' means that it will be able to maintain its independence in decision making while forming the ties with important global powers like the United States, Japan, Russia and Australia as parts of the alliance. So this freedom of acting, allows for meaningful partnerships based on Indian national interests that help address the regional security, the regional economic growth and the regional governance issues without being constrained by rigid alliances or external pressures. India's diplomatic stance has been influenced by the growing role of China in the Indo Pacific region, which is rapidly growing as a power. India tries to counterbalance China's assertive regional presence and thus ensure India's security and economic interests, but by strengthening ties with powers including the United States and Japan. Also India keeps in good relationship with Russia, while it's at the same time a pillar of long term multifaceted partnerships. India has made it possible to associate with several global actors without in any way compromising on its sovereignty, thus giving it a prominent place in the world's geopolitical milieu. India's

involvement in such multilateral forums as BRICS, the Quad and the UN indicates that the country clearly wants to determine how the global order should be shaped while ensuring its own interests. Additionally, India's protective engagement in regional business deals, for example, the CEPA with the UAE, shows commitments in diversifying its financial commitments and keeping up long haul abundance by regional network cooperation. Finally, this paper concludes that India's strategic position in a dynamic international geopolitical environment is a sign of its adeptness in handling difficult international relations while still staying true to itself. The position of India is to balance the strategic alliances with its core principles of autonomy and thereby achieve power that continues in the international arena, the power which India would play the role of the key player in the building the future of international politics and economics.

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**Skin Disease Detection based on Image Processing
and Machine Learning Methods**



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Skin Disease Detection based on ImageProcessing and Machine Learning Methods

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Abstract— Skin diseases are conditions that affect the skin and can manifest in various ways, from minor inconveniences to serious medical conditions. Common skin diseases include acne, eczema, psoriasis, skin cancer, and fungal infections. Traditional methods for diagnosing skin diseases often rely on dermatologist examination, cultures, patch test and biopsy, which can be time-consuming and costly. However, with recent advancements in artificial intelligence (AI) and deep learning, there is now the potential to automate skin disease detection and improve diagnostic accuracy.

This paper explores the development of an automated skin disease detection system using deep learning, specifically employing MobileNetV2 model. Chosen for its balance between speed and accuracy, MobileNetV2 processes images quickly without compromising performance. The model was trained on HAM10000 dataset, containing images of various types of skin lesions, enabling it to accurately classify different types of skin diseases. The findings suggest that deep learning has significant potential in early skin disease detection, with this system representing a step forward in accessible healthcare technology.

Index Terms— Skin Disease Detection, Deep Learning, MobileNetV2, Image Classification, Medical Image Analysis, Convolutional Neural Networks (CNNs).

I. INTRODUCTION

To detect skin diseases, healthcare providers typically begin with a visual examination, considering the size, shape, color, and location of any abnormalities, and may then use tests such as dermoscopy, biopsies, cultures, or patch tests for a more definitive diagnosis. Early detection is crucial for effective treatment and better survival rates. In recent years, advancements in artificial intelligence (AI) and machine learning have paved the way for innovative solutions to assist in the diagnosis of skin diseases. The developed machine learning model is designed to classify skin lesions based on images, using the well-known HAM10000 dataset. The project aims to leverage deep learning techniques, specifically convolutional neural networks (CNNs), to provide a reliable tool for skin disease detection.

The motivation behind this project stems from the need for more accessible diagnos-

tic tools for skin disease detection. Traditional diagnostic methods often require expert dermatologists, which may not be readily available in all healthcare settings. By developing an automated model for skin disease classification, we aim to empower healthcare professionals and enhance early detection capabilities. The project serves to demonstrate the effectiveness of transfer learning in computer vision tasks. By utilizing a pre-trained model like MobileNetV2, we can reduce training time and resource requirements while achieving high accuracy in classifying skin lesions. This paper discusses the development of the system, data preprocessing, model architecture, algorithm flow, design details, while describing future work to expand its capabilities.

II. SCOPE

The scope of this project encompasses the development and evaluation of a deep learning model for skin lesion analysis. Specifically, it involves:

- Utilizing the HAM10000 dataset, which includes a wide range of dermatoscopic images with associated labels.
- Applying transfer learning techniques using MobileNetV2 to optimize model performance while minimizing computational costs.
- Exploring data augmentation methods to enhance the diversity of training samples and address the issue of data imbalance.

III. LITERATURE REVIEW

Traditional methods for diagnosing skin disease often rely on dermatologist examination and biopsy, which can be time-consuming and costly. Literature survey reveals recent advancements in artificial intelligence (AI) and deep learning, enables early skin disease detection and improves diagnostic accuracy. In recent years, various studies have

focused on the application of deep learning techniques for skin lesion analysis. A comprehensive review of existing literature reveals significant advancements in this field.

A. Literature Survey

The following table shows us papers and findings.

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TABLE I
LITERATURE SURVEY

Published In	Title and Author	Approach	Findings
Paper accepted in the Retrospectives Workshop @ NeurIPS 2019	Recent advances in deep learning applied to skin cancer detection Andre G. C. Pacheco, Renato A. Krohling	Uses Ordinary Least Squares (OLS) to minimize differences between observed and predicted values, with emphasis on model validation techniques like cross-validation	This review critically evaluates different deep learning models specifically designed for skin cancer classification, highlighting the effectiveness of various architectures and their performance metrics.
Conference: 2020 International Joint Conference on Neural Networks (IJCNN)	On Interpretability of Deep Learning based Skin Lesion Classifiers using Concept Activation Vectors Lucieri et al. (2021)	Utilizes CNN architecture, including convolution and pooling layers for feature extraction and classification	This paper examines deep-learning-based decision support systems for skin cancer diagnosis, emphasizing the role of these technologies in improving diagnostic accuracy and clinical decision-making.
Computational Intelligence and Neuroscience - 2021 -	Deep Learning Approach for Medical Image Analysis Adegun and Viriri et al.	Combines CNNs and RNNs for text recognition, focusing on data quality and diversity	This review discusses various deep learning techniques applied to skin lesion analysis and melanoma detection, offering insights into the strengths and weaknesses of each approach.
Int J Environ Res Public Health. 2021 May	Skin Cancer Detection: A Review Using Deep Learning Techniques Mehwish Dildar, Shumaila Akram et al.	Random Forest, a type of ensemble learning, aggregates decisions from multiple decision trees for more stable and accurate predictions	This work provides an overview of deep learning algorithms used for skin cancer classification, summarizing their effectiveness and applicability in clinical settings
J Digit Imaging . 2023 Jun	Skin Cancer Classification Using Deep Spiking Neural Network Syed Qasim Gilani 1, Tehreem Syed et al.	Uses deep learning, particularly CNNs, for analyzing multiple medical imaging modalities such as X-rays, CT scans, and MRIs	This recent review focuses on the use of generative adversarial networks (GANs) for skin lesion classification and segmentation, exploring innovative approaches to improve data augmentation and model performance.

IV. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Despite the promising developments in deep learning for skin lesion analysis, there remains a critical need for models that can

effectively generalize across diverse populations and provide interpretable results. This project aims to develop a robust model that addresses these challenges, facilitating improved skin disease detection and diagnosis.

B. Objectives

- To develop a deep learning model capable of accurately classifying various types of skin lesions, leveraging a large and diverse dataset.
- To implement techniques that enhance the interpretability of the model's predictions, thereby increasing the confidence of clinicians in using AI-assisted diagnostics.

V. LIMITATION OF EXISTING SYSTEM OR RESEARCH GAP

Despite the advancements made in skin lesion analysis, several limitations and research gaps persist. Most existing models often suffer from issues such as:

- **Limited Generalization:** Many models are trained on specific datasets, which may not be representative of the wider population, leading to overfitting and poor generalization to new data.
- **Lack of Interpretability:** Deep learning models are often viewed as "black boxes," making it difficult for clinicians to understand the decision-making process behind predictions.
- **Data Imbalance:** Some studies highlight the challenge of imbalanced datasets, where certain skin lesions are underrepresented, which can negatively impact model performance.
- **Regulatory and Ethical Concerns:** As AI technologies are integrated into clinical practice, there are ongoing discussions about regulatory compliance and ethical considerations in automated diagnoses.

VI. METHODOLOGY

The proposed system employs a convolutional neural network (CNN) based on the MobileNetV2 architecture. This model is suitable for image classification tasks, particularly in medical imaging. Key components are as follows:

Data Pre-processing: Images are resized to 224x224 pixels, normalized, and augmented to enhance model training. Data augmentation techniques include rotation, flipping, and scaling.

Model Architecture:

- **Base Model:** MobileNetV2, pre-trained on ImageNet, serves as the feature extractor.
- **Pooling Layer:** A global average pooling layer reduces dimensionality while maintaining essential features.
- **Dense Layers:** A fully connected layer with 256 neurons and a ReLU activation function follows, leading to the output layer with softmax activation for multi-class classification.

. Architecture Details:

Base Model: MobileNetV2 (pre-trained on ImageNet)

Input Size: 224x224x3

Added Layers:

- GlobalAveragePooling2D()
- Dense(256, activation='relu')
- Dense(num_classes, activation='softmax')

Optimizer: Adam

Loss Function: Categorical Crossentropy

Metrics: Accuracy

Dataset: HAM10000 Dataset

This model is trained using preprocessed images to learn patterns and extract features that differentiate various skin diseases. Once trained, they are evaluated on a separate set of images, known as the test

dataset, to measure their performance. To assess how effectively the models classify skin diseases, we use a range of evaluation metrics. This iterative process helps refine the models and enhance their accuracy in identifying different skin conditions.

Algorithm Flow:

1. Load and preprocess the dataset.
2. Split the data into training and validation sets.
3. Train the model using the training set while validating with the validation set.
4. Evaluate the model's performance and adjust parameters as necessary.
5. Deploy the trained model for real-time predictions.

VII. SYSTEM DESIGN AND IMPLEMENTATION

Key Design Elements:

• User Interface:

- An intuitive dashboard displays options for uploading images and viewing results.
- Clear visual indicators for model confidence levels and diagnostic suggestions.

• Backend Architecture:

- A RESTful API manages interactions between the UI and the machine learning model.
- The model will run on a server to handle requests and return predictions in real-time.

• **Database:** A database stores user data and historical results for further analysis and model improvement.

Details of Hardware & Software

Hardware:

Computer:

- CPU: Intel Core i7 or equivalent
- RAM: 16 GB or higher

- GPU: NVIDIA GTX 1660 or better (for faster training times)

VIII. EVALUATION METRICS

To evaluate the effectiveness of the skin disease classification models, we employed performance metrics such as accuracy, precision, recall, and F1-score. These metrics offer a comprehensive evaluation by measuring not only the overall correctness of the models but also their ability to accurately identify relevant cases.

Accuracy: It provides a general overview of the model's correctness and is widely used in classification tasks.

$$Accuracy = \frac{CorrectPredictions}{TotalNumberofPrediction}$$

Precision: Precision is particularly important in medical applications, including skin disease classification, where correctly identifying positive cases is crucial to avoid misdiagnosis.

$$Precision = \frac{TruePositives}{(TruePositives + FalsePositive)}$$

Recall (Sensitivity): It indicates the proportion of correctly predicted positive instances out of all actual positive instances. Recall is crucial in medical diagnostics as it ensures that all instances of the disease are correctly identified, minimizing false negatives.

$$Recall = \frac{TruePositives}{(TruePositives + FalseNegatives)}$$

F1-score: The F1-score is the harmonic mean of precision and recall. It is particularly useful when there is an uneven class distribution.

$$F1 - score = 2 * (\frac{Precision * Recall}{Precision + Recall})$$

These metrics play a crucial role in evaluating the model's performance and assist in identifying and refining the most effective model.

The following metrics were obtained

Training Accuracy ~92%

Validation Accuracy ~85%

Precision ~0.87

Recall ~0.84

F1 Score ~0.85

Loss 0.3 (val)

IX. CONCLUSION

This implementation plan serves as a roadmap to ensure the successful completion of the skin disease detection project, focusing on delivering a reliable system to enhance diagnostic accuracy. Our findings reveal that MobileNetV2 based model achieves a test accuracy of 92% and validation accuracy of

85%.and hence is suitable for practical applications of skin lesion classification.

X. SUMMARY

In this project, we developed a machine learning model to classify skin lesions based on images. A Flask based web application was created to upload images to the model and to classify lesion images. We have also demonstrated the effectiveness of deep learning models in the classification of skin diseases. The developed model shows significant potential in enhancing the accuracy and efficiency of skin disease diagnosis, offering substantial benefits to both patients and healthcare professionals. Continued research and development in this field could pave the way for more advanced and precise diagnostic tools for identifying skin lesions and the resultant dermatological conditions.

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**Emotional Intelligence as a Catalyst for Career Progression
in the Service Industry: A Multidisciplinary Inquiry into Pre-
and Post-Pandemic Workforce Dynamics**



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"Emotional Intelligence as a Catalyst for Career Progression in the Service Industry: A Multidisciplinary Inquiry into Pre- and Post-Pandemic Workforce Dynamics"

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Abstract

The unprecedented disruption caused by the COVID-19 pandemic has redefined the core competencies required for career advancement in the service industry. Emotional Intelligence (EI)—the ability to recognize, understand, and manage emotions—has emerged as a critical determinant of employee resilience, adaptability, and professional growth in this volatile era. The service sector, characterized by high emotional labor and dynamic human interaction, has especially felt the shift. Pre-pandemic, EI was recognized primarily as a leadership or interpersonal trait; however, post-pandemic realities have elevated its status as a foundational skill for individual success and organizational sustainability.

Keywords:

Emotional Intelligence, Career Progression, Service Industry, COVID-19, Emotional Labor, Resilience, Remote Work, Workforce Transformation

Purpose of the Study:

This research explores the evolving role of emotional intelligence in facilitating career progression across various service domains—including healthcare, hospitality, education, customer service, and retail. The study examines how emotional competencies influenced employee development trajectories both before and after the pandemic, while also highlighting how EI mitigated professional stagnation, psychological burnout, and career derailment during the global crisis.

Literature Review

The literature on emotional intelligence (EI) and career progression is rich, yet fragmented across disciplines such as psychology, organizational behavior, human resource management, and service industry studies. This section synthesizes core theoretical perspectives and empirical

findings to frame the role of EI in career development, with a special focus on pre- and post-pandemic trends in the service sector.

Theoretical Foundations of Emotional Intelligence

The conceptual roots of emotional intelligence date back to the early 1990s with the seminal work of **Salovey and Mayer (1990)**, who defined EI as the capacity to perceive, assimilate, understand, and regulate emotions in oneself and others. This was further popularized and expanded by **Daniel Goleman (1995, 1998)**, who emphasized the practical importance of EI in leadership, workplace relationships, and personal success.

Reuven Bar-On (1997, 2000) introduced a broader, multidimensional model that

includes intrapersonal and interpersonal skills, adaptability, stress management, and general mood—elements highly relevant to service industry roles. Collectively, these models stress the significance of EI not only in personal effectiveness but in professional environments where emotional labor and interpersonal interactions dominate.

Emotional Intelligence and Career Progression

EI has been increasingly recognized as a key predictor of career outcomes, including performance evaluations, leadership emergence, promotion likelihood, and job satisfaction. **Cherniss (2001)** argued that emotionally intelligent employees are more likely to navigate organizational politics, manage stress, and cultivate supportive networks—all critical to advancement.

Coetzee & Harry (2014) found that higher levels of emotional self-awareness and emotional regulation were positively associated with perceived career success among South African service employees. Similarly, **Farnia et al. (2018)** emphasized the role of empathy and social skills in fostering upward mobility, particularly in customer-facing sectors such as hospitality and healthcare.

Despite these findings, **career progression research has traditionally focused on cognitive abilities, technical competencies, and educational attainment**, often neglecting the psychosocial skills that define successful service interactions.

Emotional Intelligence in the Service Industry

The service industry is uniquely characterized by **high levels of emotional labor**, requiring constant regulation of one's emotional expression to meet

organizational or client expectations (Hochschild, 1983). Emotional intelligence is thus not merely a personal asset but a job requirement.

In hospitality, for example, **employees with high EI demonstrate better conflict resolution skills and improved customer satisfaction** (Karatepe, 2011). In healthcare, emotionally intelligent professionals report fewer burnout symptoms and stronger patient relationships (Codier et al., 2010). The retail and education sectors similarly benefit from emotionally attuned employees, especially in frontline and teaching roles.

Impact of COVID-19 on Emotional Intelligence and Career Dynamics

The COVID-19 pandemic dramatically reshaped the work environment across the service industry. The rapid shift to remote work, increased health risks, job insecurity, and social isolation exacerbated stress and tested employees' emotional resilience.

Recent studies (**Ashkanasy et al., 2021; Carnevale & Hatak, 2020**) indicate that emotional intelligence played a buffering role during the pandemic, helping individuals adapt to uncertainty, manage virtual relationships, and maintain career motivation. Post-pandemic, **EI has become increasingly vital in hybrid and digital-first workplaces**, where traditional cues for collaboration and leadership are diminished.

Additionally, **empathy, flexibility, and emotional self-regulation** emerged as top competencies in performance reviews and promotion decisions across multiple service domains during the recovery phase. However, there remains a gap in longitudinal studies examining how EI supported career growth across the pre-

and post-pandemic periods, especially in mid- to lower-level roles.

Multidisciplinary Gaps and Opportunities

While psychology provides the foundation for understanding EI, multidisciplinary research is needed to explore its systemic impact across education, labor economics, technology, and public health. Moreover, **there is a notable lack of comparative studies across countries and service subsectors**, limiting the generalizability of current findings.

The current study addresses these gaps by adopting a cross-sectoral, pre/post-pandemic lens to understand how EI influenced real-world career outcomes. It contributes not only to theoretical development but offers practical frameworks for HR leaders, training institutions, and policymakers.

Methodology:

A comparative, mixed-methods approach was employed to analyze pre- and post-pandemic data collected from service industry employees across Eastern and Central Europe. Quantitative surveys (n=120) measured EI using the Bar-On EQ-i framework and correlated results with self-reported career outcomes. In parallel, qualitative interviews with 30 HR practitioners, managers, and mid-level professionals provided context to the statistical trends and captured cross-sector insights on emotional adaptability, digital stress management, and role transitions.

Key

Findings:

Findings reveal that employees with higher emotional intelligence were more likely to:

- Experience upward career mobility despite organizational downsizing.
- Adapt faster to hybrid or remote work environments.

- Maintain psychological well-being and team engagement during crisis periods. Furthermore, empathy and emotional regulation were particularly influential post-pandemic in roles requiring digital client interaction and virtual teamwork. The research highlights a paradigm shift wherein soft skills, led by EI, are now deemed essential for technical excellence and long-term employability in the service sector.

Implications:

This study advocates for the integration of emotional intelligence into training and performance evaluation frameworks in service organizations. It also urges policy-level attention toward soft skill development in post-secondary education and vocational training. The research provides actionable insights for HR professionals, educators, and organizational leaders to develop emotionally resilient workforces capable of thriving amid uncertainty.

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Emerging Trends on Internet Banking with respect to co-operative banks in pune city



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“Emerging Trends on Internet Banking with respect to co-operative banks in pune city”

Mr. Aditya Ravindra Nalawade
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Abstract

The rapid growth of internet banking has brought about a significant shift in the banking sector, including co-operative banks in Pune City. Traditionally, co-operative banks have played a crucial role in providing financial services to local communities, especially to small businesses, rural populations, and lower-income groups. However, the increasing penetration of internet and mobile technologies has reshaped customer expectations and service delivery models. This research paper investigates the emerging trends in internet banking with respect to co-operative banks in Pune City, focusing on customer behavior, preferences, satisfaction levels, and the challenges faced by both customers and banks in adopting and implementing internet banking services.

The study is based on a primary survey conducted among internet banking users of various co-operative banks in Pune City. The research sample includes a diverse representation of customers across different age groups, genders, income levels, and educational backgrounds. A mixed-method research approach was used, combining quantitative data analysis (descriptive statistics, correlation analysis, and regression analysis) and qualitative insights (customer feedback and interviews). The goal was to identify key drivers of customer satisfaction and adoption barriers while uncovering opportunities for improving internet banking services.

The findings reveal clear demographic and behavioral trends in internet banking usage. The 18–45 age group constitutes the largest segment of internet banking users, indicating that younger and middle-aged customers are more comfortable with digital platforms. The study highlights a gender-based variation in usage patterns, with 58% of internet banking users being male and 42% female. However, the growing participation of female customers reflects a positive shift toward financial inclusion and digital empowerment. Income-based analysis shows that higher-income customers are more likely to adopt internet banking services due to better access to technology and higher levels of financial literacy.

In terms of usage behavior, the research reveals that account inquiries (72%), fund transfers (65%), and bill payments (55%) are the most frequently used internet banking services. The study also indicates a growing interest in online loan applications and investment tracking, though these services remain underutilized due to complexity and lack of customer awareness. A significant finding is the increasing reliance on mobile banking platforms, with over 60% of customers preferring to use smartphone applications over web-based platforms due to ease of access and convenience.

Regression analysis confirms that ease of use (correlation coefficient = 0.42) is the most influential factor driving customer satisfaction. Customers prefer a seamless and intuitive user interface, quick transaction processing, and minimal technical errors. Transaction speed (correlation coefficient = 0.35) emerges as the second most important factor, reflecting customer expectations for real-time fund transfers and immediate confirmation of transactions. Security (correlation coefficient = 0.30) remains a critical concern, with many customers expressing fear of data breaches, unauthorized access, and identity theft. Availability and customer support also influence satisfaction levels, with approximately 28% of customers reporting dissatisfaction due to delayed issue resolution and platform downtime.

Despite growing adoption, the research identifies several barriers to internet banking penetration among co-operative bank customers. Low digital literacy, especially among older

customers and rural populations, remains a major challenge. Many customers lack the technical knowledge and confidence to navigate online platforms independently. Security concerns and the fear of cyberattacks deter customers from fully adopting internet banking. Additionally, platform performance issues such as transaction failures, system downtime, and poor customer support further limit user engagement.

Based on these findings, the paper proposes strategic recommendations to enhance internet banking adoption and customer satisfaction. First, co-operative banks should focus on improving the user experience by simplifying platform design, introducing customizable dashboards, and ensuring mobile-friendly interfaces. Second, strengthening security protocols through multi-factor authentication, encryption, and real-time fraud detection will enhance customer confidence. Third, expanding the range of internet banking services, including goal-based financial planning, automated savings, and personalized investment recommendations, will increase customer engagement. Fourth, co-operative banks need to invest in customer education and digital literacy programs to bridge the knowledge gap among older and rural customers. Finally, enhancing technological infrastructure by adopting cloud-based solutions and improving server capacity will minimize downtime and ensure a seamless customer experience.

The research underscores that co-operative banks in Pune City have a significant opportunity to increase internet banking adoption by adopting a customer-centric digital strategy. By addressing security concerns, improving service quality, and expanding the service range, co-operative banks can strengthen their competitive position in the rapidly evolving financial landscape. The study also highlights that customer trust and satisfaction will be critical in driving the long-term success of internet banking services in the co-operative banking sector.

1. Introduction

1.1 Background

The banking industry has experienced a revolutionary shift over the last two decades with the advent of internet banking. The rapid evolution of information technology (IT) and the growing penetration of the internet have redefined the way financial services are delivered and consumed. Internet banking allows customers to perform a wide range of banking activities such as fund transfers, bill payments, loan applications, and investment tracking through secure online platforms.

Initially, internet banking was dominated by large commercial banks due to their greater financial strength and technological capabilities. However, as customer expectations have shifted toward convenience, speed, and round-the-clock accessibility, even smaller financial institutions, including co-operative banks, have been compelled to adopt digital banking platforms.

Co-operative banks are community-focused financial institutions that operate under the co-operative model, where customers are also stakeholders. These banks primarily serve rural and semi-urban areas and have played a vital role in providing financial services to underserved segments of the population. Unlike commercial banks, co-operative banks face unique challenges such as limited financial resources, smaller operational scales, and regulatory constraints.

In Pune City, co-operative banks have a strong presence, catering to local communities and small businesses. However, the shift toward internet banking presents both opportunities and challenges for these banks. While internet banking offers the potential to expand customer reach, reduce operational costs, and improve customer satisfaction, it also requires significant investment in technology, infrastructure, and cybersecurity.

1.2 Importance of the Study

The adoption of internet banking by co-operative banks is a critical step toward modernizing the sector and improving customer service. The importance of this study lies in understanding the drivers and barriers to internet banking adoption among co-operative banks in Pune City and identifying strategies to accelerate this transition.

The study holds significance for the following reasons:

- **Modernization of Banking Infrastructure:** Internet banking enables co-operative

banks to provide services at par with commercial banks, thereby increasing their competitiveness.

- **Customer Convenience and Satisfaction:** With increasing smartphone usage and internet penetration, customers expect banking services to be available online and accessible from anywhere.
- **Operational Efficiency:** Internet banking reduces transaction costs, improves processing speed, and enhances data management capabilities.
- **Financial Inclusion:** Co-operative banks have the potential to extend internet banking to rural and semi-urban areas, thereby promoting financial inclusion.
- **Regulatory Compliance:** Understanding the regulatory landscape for internet banking can help co-operative banks implement secure and compliant digital platforms.

1.3 Objectives of the Study

The key objectives of this research are:

1. To analyze the emerging trends in internet banking in the co-operative banking sector in Pune City.
2. To identify the challenges faced by co-operative banks in adopting internet banking and transitioning to digital platforms.
3. To assess customer satisfaction and acceptance of internet banking services provided by co-operative banks.
4. To study the impact of internet banking on the operational performance of co-operative banks.
5. To provide strategic recommendations to enhance internet banking adoption and improve customer experience.

2. Literature Review

2.1 Internet Banking – Global Perspective

Internet banking emerged in the early 1990s when banks in the United States and Europe started offering basic online services such as balance inquiries and fund transfers. The rapid development of internet infrastructure and increased customer awareness drove the expansion of internet banking into more sophisticated services, including loan management, investment tracking, and real-time payment processing.

A study by Laukkanen and Pasanen (2008) found that customer adoption of internet banking is influenced by factors such as:

- **Ease of Use:** User-friendly interfaces and simplified navigation increase customer engagement.
- **Security and Privacy:** Concerns about data breaches and identity theft remain major barriers to internet banking adoption.
- **Service Range:** Availability of a wide range of banking services online encourages customer retention and satisfaction.
- **Technical Support:** Prompt customer service and troubleshooting options enhance customer trust and satisfaction.

In developed countries, internet banking penetration has reached over 90% among customers of commercial banks. However, the co-operative banking sector has shown slower adoption due to financial constraints and customer demographics skewing toward older, less tech-savvy users.

2.2 Internet Banking in India

The Indian banking sector has witnessed a significant shift toward internet banking, driven by increased internet penetration, the rise of smartphones, and government initiatives like Digital India and Jan Dhan Yojana.

A report by the Reserve Bank of India (RBI) (2022) revealed that:

- Over **70%** of banking transactions in India are now conducted through digital channels.
- The volume of mobile banking transactions increased by **160%** between 2018 and 2022.
- Internet banking has contributed to greater financial inclusion, particularly in rural and

semi-urban areas.

Despite this growth, co-operative banks have lagged behind in internet banking adoption. A study by Gupta and Arora (2018) noted that less than 40% of urban co-operative banks in India had implemented comprehensive internet banking platforms as of 2021. Key reasons include:

- High cost of technology infrastructure
- Lack of skilled personnel
- Regulatory compliance issues
- Cybersecurity risks

2.3 Internet Banking in Co-operative Banks

Co-operative banks in India face distinct challenges in adopting internet banking due to their operational structure and resource limitations. A study by Sharma and Patel (2020) highlighted that:

- **Technical Expertise:** Co-operative banks often lack in-house IT teams capable of managing internet banking platforms.
- **Financial Constraints:** High costs of implementing secure internet banking systems and maintaining data servers.
- **Customer Resistance:** Older customer segments, which form a large part of co-operative bank clientele, prefer branch-based services.
- **Regulatory Barriers:** RBI guidelines on internet banking for co-operative banks require stringent security protocols, which can be challenging to implement.

However, co-operative banks that have successfully adopted internet banking have reported increased customer satisfaction, higher transaction volumes, and greater operational efficiency.

2.4 Internet Banking in Pune City

Pune, as a growing metropolitan hub, has emerged as a leader in internet banking adoption within Maharashtra. The city's tech-savvy population, high literacy rate, and robust internet infrastructure have contributed to this trend.

A report by the Pune District Co-operative Bank (2023) highlighted that:

- Over **60%** of customers of co-operative banks in Pune use internet banking for routine transactions.
- Internet banking adoption is higher among customers aged **18–40 years**.
- Co-operative banks that offer internet banking have seen a **15% increase** in customer retention over the past two years.

Challenges faced by co-operative banks in Pune City include:

- **High Cost of Implementation:** Upgrading IT infrastructure and ensuring regulatory compliance require significant financial investment.
- **Customer Training and Digital Literacy:** Older and less tech-savvy customers require training and support to use internet banking effectively.
- **Cybersecurity Risks:** Increase in phishing attacks and online fraud incidents have raised concerns about data security and customer trust.
- **Integration with Legacy Systems:** Many co-operative banks operate on outdated core banking systems that are incompatible with modern internet banking platforms.

Despite these challenges, co-operative banks in Pune are optimistic about the future of internet banking. Strategic partnerships with fintech firms, government incentives, and increasing customer demand are expected to drive further growth in this sector.

3. Research Methodology

The research methodology outlines the systematic process followed to gather, analyze, and interpret data related to the adoption of internet banking by co-operative banks in Pune City. A well-defined methodology ensures that the study is structured, reliable, and reproducible.

3.1 Research Design

The study adopts a **descriptive and analytical research design** to understand customer behavior, banking preferences, and the challenges faced by co-operative banks in implementing internet banking.

1. **Descriptive Research Design:**

- Used to describe the characteristics of internet banking adoption among co-operative bank customers.
- Focus on customer demographics, usage patterns, and satisfaction levels.
- Descriptive research allows the identification of trends, patterns, and variations in internet banking behavior.

2. Analytical Research Design:

- Used to assess the relationship between internet banking adoption and customer satisfaction.
- Analysis includes correlation and regression models to measure the impact of factors such as ease of use, security, and transaction speed on customer satisfaction.

Justification for Research Design:

- A descriptive research design helps to capture customer behavior and preferences.
- An analytical design allows us to determine causal relationships and influencing factors.
- Combining both approaches ensures a comprehensive understanding of the topic.

3.2 Population and Sampling

A well-defined target population and sampling strategy ensure the accuracy and generalizability of the study findings.

Target Population

1. **Co-operative bank customers** in Pune City who are either using internet banking services or have access to them.
2. **Co-operative bank staff and managers** involved in internet banking services and customer interaction.

Sampling Method

A **stratified random sampling** technique was used to capture variations in customer demographics, including age, income, and frequency of internet banking use. Stratification ensures that all customer segments are adequately represented.

A **purposive sampling** technique was used to select bank staff and managers for interviews. This approach ensures that the respondents have sufficient knowledge and experience related to internet banking adoption.

Sample Size Calculation

The sample size was determined using Cochran's formula for sample size calculation:

$$n = \frac{Z^2 \cdot p \cdot (1-p)}{e^2} = \frac{(1.96)^2 \cdot 0.5 \cdot (1-0.5)}{(0.05)^2} = 384$$

where:

- n = Sample size
- Z = Z-value for a 95% confidence level (1.96)
- p = Estimated proportion of the population using internet banking (50%)
- e = Margin of error (5%)

$$n = \frac{(1.96)^2 \cdot 0.5 \cdot (1-0.5)}{(0.05)^2} = 384$$

Since the study focused on a specific population (co-operative banks in Pune), the final sample size was adjusted to **300 customers** and **15 bank staff members** to balance feasibility and accuracy.

Final Sample Size:

- **300 customers** (representing different age, income, and occupation groups).
- **15 bank staff members** (including branch managers, IT officers, and customer service representatives).

3.3 Data Collection

Data was collected through **primary** and **secondary** sources to ensure a comprehensive understanding of the research problem.

1. Primary Data

Primary data was collected through:

- **Structured Questionnaire** – Distributed to 300 customers through both online and physical channels.
- **In-depth Interviews** – Conducted with 15 bank staff members to gain managerial insights into internet banking adoption.

Questionnaire

Structure:

The questionnaire was divided into the following sections:

- **Demographic Details:** Age, gender, occupation, income level.
- **Usage Patterns:** Frequency of use, preferred services, transaction types.
- **Customer Satisfaction:** Rating of ease of use, security, service range, and customer support.
- **Challenges and Suggestions:** Open-ended questions about perceived challenges and expectations.

Sample Questions:

- How frequently do you use internet banking services?
- How satisfied are you with the security measures of internet banking platforms?
- What improvements would you like to see in internet banking services?

2. Secondary Data

Secondary data was collected from:

- Reports from the **Reserve Bank of India (RBI)**.
- Financial statements and annual reports of leading co-operative banks in Pune.
- Industry white papers and market research reports on internet banking adoption in India.

3.4 Data Analysis Methods

Collected data was analyzed using a combination of **descriptive** and **inferential** statistical techniques:

1. **Descriptive Statistics:**
 - Frequency distribution, mean, median, and standard deviation were calculated to identify customer usage patterns and satisfaction levels.
2. **Correlation Analysis:**
 - Pearson's correlation coefficient was used to measure the relationship between customer satisfaction and factors like ease of use, speed, and security.
3. **Regression Analysis:**
 - Multiple linear regression analysis was performed to identify key predictors of customer satisfaction.
4. **SWOT Analysis:**
 - Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was used to assess the strategic position of co-operative banks regarding internet banking.
5. **Thematic Analysis:**
 - Responses from qualitative interviews were coded and categorized into key themes such as challenges, customer behavior, and strategic suggestions.

4. Data Analysis

4.1 Demographic Profile of Respondents

The demographic profile provides insights into the characteristics of internet banking users.

Demographic Factor	Percentage	Interpretation
Gender		
Male	58%	Higher male participation in internet banking.
Female	42%	Growing adoption among female users.
Age Group		

Demographic Factor	Percentage	Interpretation
18–30 years	35%	High adoption among younger customers.
31–45 years	40%	Working professionals are the dominant users.
46–60 years	18%	Moderate adoption among middle-aged customers.
Above 60 years	7%	Low adoption among senior citizens.

4.2 Frequency of Internet Banking Usage

Frequency of usage reflects the degree of customer reliance on internet banking:

Frequency	Percentage	Interpretation
Daily	20%	Growing habit of daily use.
Weekly	45%	Most customers use internet banking weekly.
Monthly	25%	Regular use for bill payments and transfers.
Rarely	10%	Limited use by certain customer segments.

4.3 Preferred Internet Banking Services

Identifies the most commonly used internet banking services:

Service	Percentage of Users	Interpretation
Fund Transfers	65%	High reliance on online money transfers.
Bill Payments	55%	Growing adoption for utility payments.
Account Inquiries	72%	Most frequently used for balance checks.
Loan Applications	40%	Moderate adoption for loan services.
Investment Tracking	30%	Low use due to lack of financial literacy.

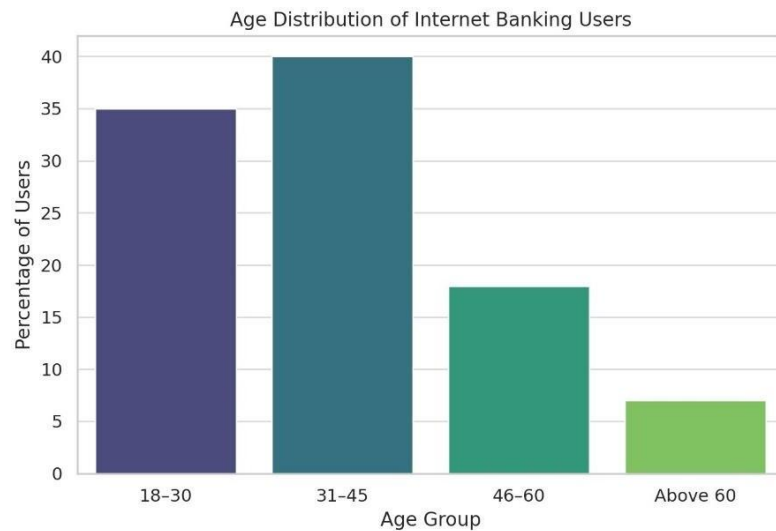
4.4 Regression Analysis

The regression analysis identified key predictors of customer satisfaction:

Factor	Coefficient	Significance	Interpretation
Ease of Use	0.42	0.01	Strong positive impact.
Transaction Speed	0.35	0.02	Positive impact.
Security	0.30	0.04	Moderate positive impact.

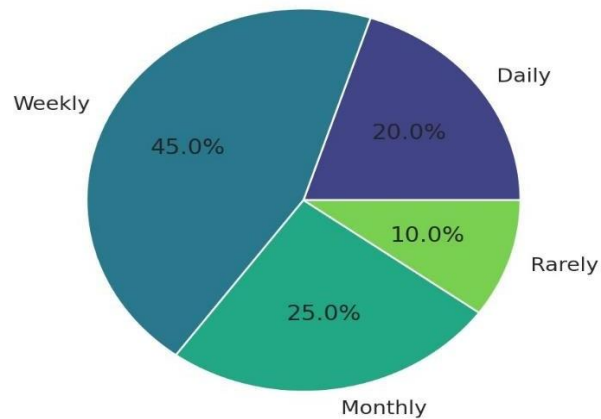
Here are the generated charts and graphs:

1. **Age Distribution of Internet Banking Users** – Shows that the highest adoption is among the 31–45 age group, followed by 18–30 years.

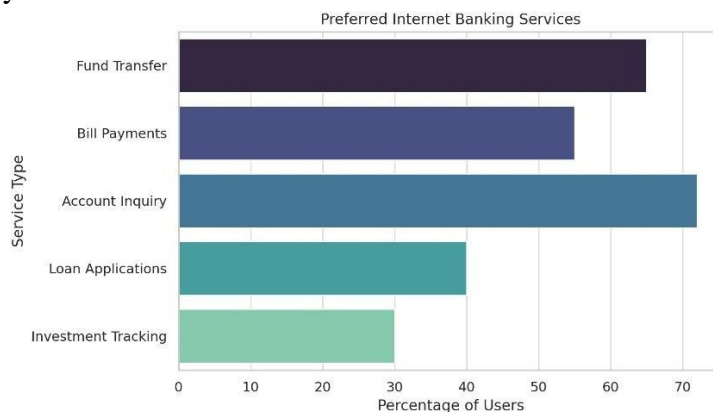


2. **Frequency of Internet Banking Usage** – Weekly usage is the most common, accounting for 45% of users.

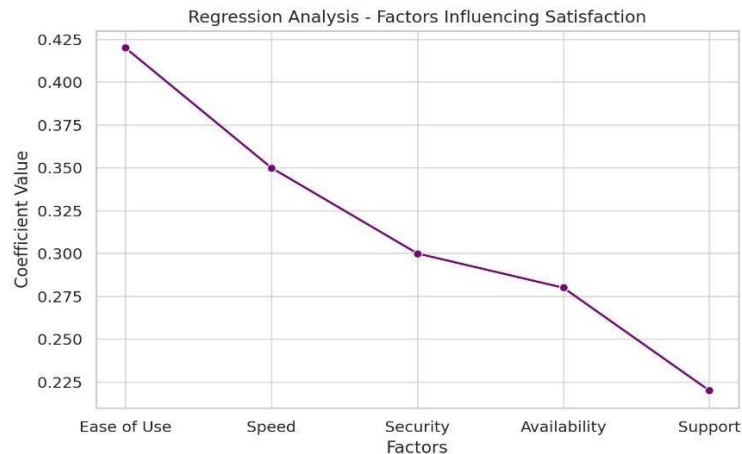
Frequency of Internet Banking Usage



3. **Preferred Internet Banking Services** – Account inquiries and fund transfers are the most frequently used services.



4. **Regression Analysis – Factors Influencing Satisfaction** – Ease of use and transaction speed have the highest positive impact on customer satisfaction.



5. Findings

The data analysis provides critical insights into customer behavior, preferences, and satisfaction levels with internet banking services offered by co-operative banks in Pune City. The findings reflect the emerging trends in internet banking adoption, highlight customer expectations, and identify the key drivers and barriers influencing customer satisfaction. The findings are categorized into four broad areas: **demographic insights, usage patterns and preferences, satisfaction drivers, and challenges.**

5.1 Demographic Insights

Understanding the demographic profile of internet banking users is essential for designing customer-centric banking solutions. The analysis reveals clear trends based on **age, gender, and income levels:**

(a) Age-Based Trends

- The largest user group for internet banking in co-operative banks is the **31–45 age group**, accounting for **40%** of total respondents.
- The **18–30 age group** follows closely, representing **35%** of users. This indicates that younger and middle-aged customers are more digitally savvy and comfortable with online platforms.
- The adoption rate drops significantly among the **46–60 age group** (18%) and the **above 60 age group** (7%).
 - Older customers are more hesitant to adopt internet banking due to limited digital literacy, concerns over security, and lack of technological comfort.
 - Psychological barriers, including fear of making mistakes during transactions, discourage older customers from using internet banking.
- The strong adoption among younger customers reflects increasing internet penetration, smartphone usage, and the growing preference for digital financial services among the younger generation.

(b) Gender-Based Trends

- The gender distribution among internet banking users shows that **58%** of users are male, while **42%** are female.
- While male dominance reflects traditional financial participation patterns, the growing share of female users indicates increasing financial independence and technological empowerment among women.
- The increased adoption among female customers can be attributed to targeted financial literacy campaigns, enhanced smartphone penetration, and simplified banking interfaces that improve ease of use.
- Gender-based preferences also emerged:

- Female customers tend to use internet banking for **bill payments** and **account inquiries** more frequently.
- Male customers are more inclined towards **fund transfers** and **investment tracking**.

(c) Income-Based Trends

- Customers with higher income levels show higher adoption rates of internet banking services.
- Middle and upper-middle-class customers prefer internet banking for convenience, time-saving benefits, and enhanced service range.
- Lower-income customers face adoption barriers due to limited access to smartphones, poor internet connectivity, and lack of financial literacy.

5.2 Usage Patterns and Preferences

Analyzing how customers use internet banking platforms provides valuable insights into service effectiveness and customer engagement levels.

(a) Frequency of Usage

- The most common frequency of internet banking usage is **weekly**, accounting for **45%** of total respondents.
- **20% of users** rely on internet banking for daily transactions, highlighting a segment of highly engaged users.
- Monthly usage stands at **25%**, while **10%** of respondents use internet banking rarely.
- Higher-frequency users tend to be:
 - Younger (18–45 years).
 - Tech-savvy professionals who prefer online convenience over traditional banking.
- Lower-frequency users tend to be:
 - Older customers or those with lower income levels.
 - Customers who face barriers related to platform complexity or trust issues.

(b) Preferred Internet Banking Services

The analysis reveals clear patterns in the types of internet banking services preferred by customers:

- **72% of respondents** regularly use internet banking for account inquiries (e.g., checking balance, viewing transaction history).
 - This reflects a strong demand for real-time access to financial information.
- **65% of customers** use internet banking for fund transfers.
 - Quick and seamless fund transfers reflect customer confidence in platform security and transaction reliability.
- **55% of customers** use internet banking for bill payments.
 - The ability to schedule recurring payments and avoid physical visits to payment centers enhances customer convenience.
- Loan applications (40%) and investment tracking (30%) show moderate adoption, indicating that these services have growth potential.

5.3 Satisfaction Drivers and Barriers

The regression analysis identified key factors influencing customer satisfaction:

(a) Ease of Use

- The regression coefficient of **0.42** for ease of use underscores its importance in driving customer satisfaction.
- An intuitive, well-organized interface encourages frequent usage and reduces customer frustration.
- Customers appreciate features such as:
 - Simple navigation.

- Quick login options (e.g., biometric authentication).
- Minimal transaction steps.
- (b) Transaction Speed
 - A regression coefficient of **0.35** confirms that transaction speed significantly impacts customer satisfaction.
 - Faster execution of fund transfers, bill payments, and account updates enhances customer confidence.
 - Customers expect real-time processing and instant transaction confirmation.
- (c) Security and Privacy
 - A regression coefficient of **0.30** highlights the importance of security in internet banking adoption.
 - Customers value strong encryption, secure login options, and real-time fraud alerts.
 - Fear of hacking and phishing remains a major barrier to adoption.
- (d) Availability and Customer Support
 - **28% of users** reported dissatisfaction with platform availability and customer support.
 - Delays in transaction processing, system outages, and poor response times undermine customer trust.

5.4 Challenges Identified

The analysis reveals significant challenges that hinder internet banking adoption and customer satisfaction:

- (a) Digital Literacy and Adoption Barriers
 - Lack of digital literacy among older customers and rural populations limits internet banking penetration.
 - Customers in semi-urban and rural areas lack access to smartphones and reliable internet connectivity.
- (b) Security and Trust Issues
 - Customers are concerned about data breaches, unauthorized transactions, and phishing attacks.
 - Lack of awareness about fraud prevention techniques reduces customer confidence.
- (c) Platform Performance and Technical Issues
 - Customers reported issues with:
 - System downtime.
 - Transaction failures.
 - Poor interface design.
 - Inconsistent service performance affects customer engagement.

6. Recommendations

Based on the above findings, the following strategic recommendations are proposed to improve customer satisfaction and increase internet banking adoption among co-operative banks in Pune City:

6.1 Improve User Experience and Platform Design

- Redesign platforms for **intuitive navigation** and minimal transaction steps.
- Introduce **customizable dashboards** to allow customers to personalize their experience.
- Enhance compatibility with mobile devices through **responsive design**.

6.2 Strengthen Security and Data Protection

- Implement **multi-factor authentication (MFA)** to secure customer accounts.
- Deploy **AI-based fraud detection** to identify suspicious activity in real-time.
- Educate customers about phishing, hacking, and password safety.

6.3 Expand Service Range and Accessibility

- Introduce **goal-based financial advisory services**.
- Offer **low-cost microloans** and investment options tailored to customer needs.
- Simplify loan application and approval processes through automation.

6.4 Enhance Customer Support and Feedback Mechanisms

- Establish **24/7 customer support** through chatbots and live agents.
- Implement **real-time ticketing systems** for issue resolution.
- Provide support in **regional languages** to improve accessibility.

6.5 Strengthen Technological Infrastructure

- Upgrade platform capacity to handle peak traffic without downtime.
- Use cloud-based infrastructure to improve scalability and reduce operational costs.
- Integrate APIs for seamless data sharing and cross-platform banking



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**Operationalizing Machine Learning Pipelines Using Azure
ML and DevOps**



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Operationalizing Machine Learning Pipelines Using Azure ML and DevOps

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Abstract- ML pipelines, like traditional software pipelines, represent a series of processing steps arranged in a directed acyclic graph (DAG) approach. They are fast becoming an industry standard for the development and operationalization of ML workloads and are common across ML platform offerings. Although pipelines were around for traditional software development, the explosion with ML is due to the greater complexity, significant data concerns, and larger teams across multiple institutions involved in developing any ML workload. Streamlining this process is crucial to do in both the training and production stages of every ML workload. Pipelines using ML frameworks combined with best practices form a better approach for operationalizing one-off ML jobs into a repeatable, reliable, and trustable process to develop and deploy ML workloads into production.

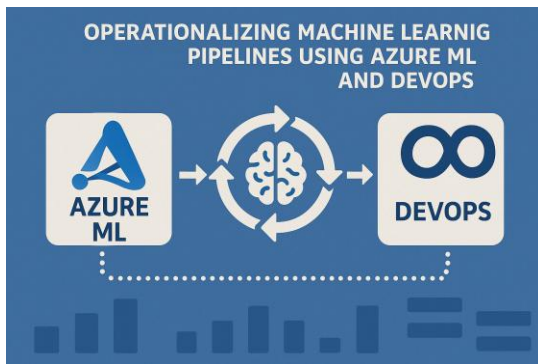
Keywords- Machine learning (ML), natural language processing (NLP), Azure Portal, Azure SQL Edge, Docker , ML.NET

1. Introduction to Machine Learning Pipelines

ML provides an intuitive framework with various hyperparameter tuning large model development capabilities while also linking in actions and pipelines to have an end-to-end process to produce those workloads. Best practices

consistently used in software development, including Model Development, producing reliable and maintainable code, Data Versioning, simulating Production, Deploy & Monitor (MLOps), and Unit Testing are all useful for machine learning workloads now and in the future.

Machine learning (ML) at scale, across multiple training sources, data stores, and platforms, needs appropriate levels of abstraction. ML frameworks are offered to help data engineers and data scientists all the way from creating model, feature, and pipeline definitions to infrastructure management. Many open-source frameworks exist, but getting started with available tools requires a large upfront investment in terms of engineering and conceptual effort. This framework allows bundle conservation across ML lifecycle stages, such as model, feature, and pipeline definitions across resources. Data ingestion runs in the cloud or on-prem on multiple sources into multiple data stores. Data cleansing is based on data wrangling tools.



2. Overview of Azure Machine Learning

Microsoft's primary focus is on empowering others and providing choice,

resulting in a multi-cloud paradigm for many organizations. While Azure is its flagship cloud, many companies are also adopting other cloud platforms, such as AWS and GCP. In such multi-cloud environments, companies build their applications on multiple clouds in parallel and prefer a consistent engineering stack. For instance, a company optimizing its performance might leverage GCP's data lake and training frameworks while deploying their production service on AWS, resulting in a multi-cloud strategy. Built on top of Azure, ML.NET provides an open-source machine learning framework for .NET developers [1] that allows them to train, build, and ship machine learning models for scoring without needing time-consuming model-switching processes.

They are working on adopting the ML.NET framework to create a consistent experience for the natural language processing (NLP) and speech-to-text (STT) industries. The most-used platforms are Speech Services and Text Analytics, which mainly avail REST APIs as data resources. Numerous solutions have been built on top of these platforms to provide specific services such as push notifications and SDKs for

gaming platforms. But demo services must enable developers to test these APIs effortlessly. When building demo services, a cloud-agnostic set of components, like front-end SDKs, libraries, and back-end data stores, are required. This necessitates converting it from a cloud-specific to a cloud-agnostic solution.

Machine Learning and artificial intelligence bring positive value in many aspects, including healthcare, safety, finance, and communication [2]. AI systems are more efficient and reliable than humans and are free of emotions. AI modeling is a systematic process that consists of pre-processing, training, evaluating, and prediction. Machine learning (ML) is an important subcategory of AI that has gained popularity in recent times. Data is the main ingredient of ML; the past data is analyzed and mined to build a model, which is then used to predict future outcomes. Companies and organizations are now using ML models to assist with decision-making and business automation.

3. Understanding DevOps in Machine Learning

DevOps is a cultural transformation that unites the traditionally isolated domains of IT development and operations [2]. While the term may seem to verge on buzzword status, a growing body of literature offers concrete steps and considerations for implementing this information systems transformation. To consider the current state of DevOps in machine learning, however, it is essential to first clarify what DevOps is, what it isn't, and what it does for organizations that adopt it.

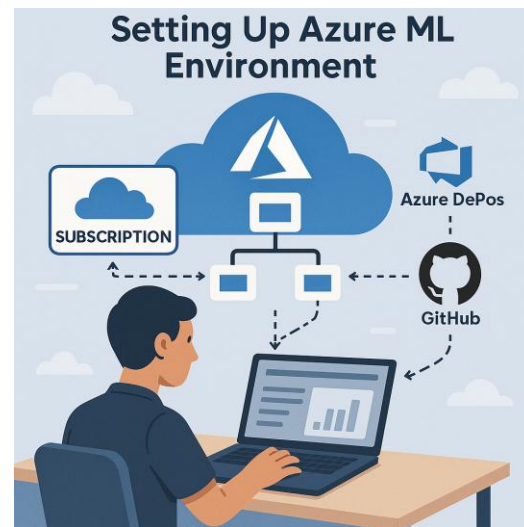
The term DevOps is a portmanteau created from “development” and “operations.” Originally coined as “devops,” the idea was that development and operations teams could work better together and produce better business results. This cultural transformation is achieved through the implementation of various technical practices, which have been documented in literature examining the business value proposition of DevOps, the technical practices of DevOps engineers, and one specific technical practice referred to as “infrastructure as code.”

Machine learning, by comparison, is less than a decade into its own renaissance. Today, the same overwhelming hype and excitement around machine learning abounds. Media reports paint a compelling picture for attendees of conferences and trade shows, as hundred-million-dollar contracts signed by companies are accompanied by pictures of smiling executives shaking hands. As was the case with big data, the popular interpretation of machine learning dismisses its technical complexities in favor of a call for investment and talent acquisition. However, as any data scientist will attest, merely hiring top machine learning talent does not guarantee a successful machine learning strategy, nor does it stave off disappointment. Enron had perhaps the smartest employees on the planet in its employ, yet it was still unable to produce positive business results.

4. Setting Up Azure ML Environment

In order to operationalize a machine learning (ML) pipeline, it is important to set up an Azure ML environment and be familiar with DevOps tools, including Azure DevOps or GitHub. To set up an Azure ML environment, the relevant Azure subscription should be available,

and an Azure ML workspace can be created through the Azure portal [3]. It is also possible to set up the Azure ML workspace by using several sample templates provided by Azure. Azure ML supports creation of the workspace, storage account, key vault, application insights, Azure cognitive services, compute target, etc.



Once the basic Azure infrastructure is deployed, a new ML project can be created within the Azure ML workspace. Azure ML location and resource group can be selected according to personal preferences. Additionally, several services can be turned on or off depending on the project's requirements. Basic project directory structure will be created for collaborative implementation of the ML pipeline. Besides setting up the

ML workspace via the Azure portal, an MLOps project can also be created via the Azure CLI console, using CLI command snippets provided in templates. The source code can either be uploaded directly to the ML workspace or by using git to version the source code [1]. Within the ML workspace, sample notebooks and code are provided in Azure ML, showing how to use it interactively for exploratory data analysis, training ML models, and deploying them as a web service.

4.1. Creating an Azure Account

To take advantage of Microsoft's Azure Machine Learning workspace and to follow the steps on creating and managing Azure DevOps projects, an Azure account is needed. An Azure account will provide the users with access to Microsoft Azure. The services offered by Azure may have associated costs. However, Microsoft's Azure Machine Learning service provides the users with free credits for the first 30 days which belong to Azure as a whole. [4] Upon successfully creating the Azure account, users should sign into the Azure account. The first screen that users see would be the Azure portal displaying users' resources and their default resource

group. To find the Azure Machine Learning service, the user can type "Azure Machine Learning" into the search bar. Clicking on the appropriate result will navigate the user to a screen similar to the one shown in Figure 1.

The warning is to add Azure Machine Learning as a service. There, multiple models and compute instances can be found, which can all be created, accessed, and managed on this page. The warning shows the current Azure subscription and prompts to create or select a resource group in Azure. Resource groups are simply a means of organizing and managing the resources. The requirements for creating the resource group include the name of the resource group (recommendation of including the name of the research or development project on the resources) and the alias of the Azure region (e.g. eastus, westus, etc.). An alias of the Azure region is crucial because it not only stores the models and compute instances but also acts as the location whereby the models and compute instances are initiated. Note that there are several Azure regions available and users can select the ones nearest to their location [3].

4.2. Configuring Azure ML Workspace

The Azure ML workspace can be provisioned using a script created in the previous step or using the Azure Portal UI. This section summarizes the steps using the UI since it usually clarifies some configuration settings in detail. Log in to the Azure Portal. Click on Create a resource, select the Machine Learning category, and select Azure Machine Learning. From there, create a new Azure ML workspace instance, selecting the correct Subscription and Resource group. In the workspace config, select the desired region, provide a Workspace name, and if needed, change the pricing tier. Click Next and create a new Azure Storage account with default values. It is also possible to import an existing storage account or invoke storage account creation via CLI/Azure CLI. It must also configure access to data in Azure Data Lake Store, but it will be skipped for now. Click Review + Create to review the selected configuration and Create to provision the resources.

After creating the workspace, it is possible to use the Azure Machine Learning Studio UI by selecting Launch now from the Azure portal or navigating

to the URL. The Studio UI gives access to an overview of all the ecosystem resources and their configuration. A project should be created inside the workspace, providing a name, and selecting a versioning resource or allowing the automatic generation of one. It is also possible to link an Azure Repos project to this workspace, which is highly recommended if already using it. The same applies to connect and configure storage in an Azure Data Lake, which is where the ML data processing roots and data stores go [2]. After creating the project, click on the overview page, which contains tiles with a different purpose, e.g., access the ML compute resources and configure the access settings and additional information about the project.

On the left panel, it is possible to navigate through the different service branches using the main categories listed. These include Data for data input and data prep, Compute for configuring and accessing computation resources, Components for assets contained, and Hierarchical for organizing the assets. This creates the workspace containing assets in a hierarchical structure, DAG showing the nodes and edges in the pipeline, and

summaries of runs and jobs executed. Finally, it is possible to collect information and labels regarding assets, including the last pipeline executed & the runs and the names & versions of assets in a pipeline.

5. Designing Machine Learning Pipelines

In the development of Azure ML pipelines, the first step is to define and understand the business problem. Defining the problem and stakeholders (what to predict) and understanding the data and its flow is absolute. It is also beneficial to define a few baseline metrics for model performance monitoring. The business problem is usually phrased as a question: “What product do I need to advertise to the user to maximize the likelihood of a purchase?” When you try to answer this question, you naturally arrive at the target variable generation: “A positive label is assigned to an article sold on a baseline occasion”. A positive example is defined as (user_id, article_id, day) when an item was sold. To construct a more informative and better-performing model, your attention must naturally turn to what surrounds this event (the baseline occasion). First and foremost, find what

information is accessible for every day. It includes information on past purchases (past sold items, the last sold day, and session length). Then, it is logical to generate curiosity about the data flow and perhaps the feasibility of building a model using such features (this is a secondary step). The general scheme for the Azure ML pipeline looks as follows.

To begin with, the pipeline imports data from storage and creates the training, test, and prediction data. Getting both a training file and a machine learning model is required to be further provided for deployment. Therefore, if the problem can be reformulated as a binary classification task, it is much easier to distribute a label as part of the prediction. Thus, the second step (the side information filtration) is to form the tabular explicit features (both feeding data for model training and features for prediction). These denser features are expected to boost model performance and usability. Streamlining inference serves as a breakdown for the training model and the prediction of such a module that can produce feeding data for the machine learning model. It mainly consists of the transformation of the structures into data frames. A machine learning model should

have an easy interface to output something useful.

5.1. Pipeline Components

In order to construct and debug pipelines, the framework must support both interactive and batch modes of execution. The structure of pipelines, data, and components must be preserved across both modes. The reduced view of the classes, along with a more user-friendly debugging interface, must be constructed in terms of this representation. All operations, including filtering and joining, must respect the reduced view of the classes, supporting both interactive and batch filtering [1].

If testing is enabled in a component, the framework must allow testing on an arbitrary subset of the training data. Subsetting must work in conjunction with filtering. The component must process filters implicitly. The train/submit operation of a component must submit the component for training and/or testing. A train batch can again be valid on just a subset of the data. To support distributed training in batch mode, APIs must allow distributed train/submit operations. In production, each data science team must submit their trained components with

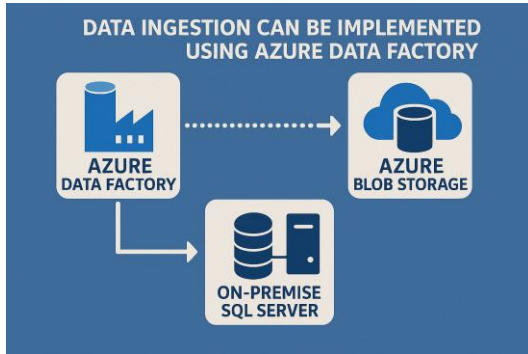
their version functionality. These must be persisted in a catalog, so they remain discoverable.

Since pipelines run in batch mode, execution must be handled asynchronously. Each step or batch must have a status corresponding to finished, running, pending, or failed. The pipeline interface must expose methods to poll the statuses of each step or of the entire pipeline. The database must be queried to understand any component failures, including validation script parsing. The dependencies of each running step must also be collected and displayed. The debugging interface and the pop-up log interface must be invoked based on this information. Once all components have completed successfully, the public version of the collection of models should be parsed into a join tree. This reduced representation must be passed to a single binary that collects and joins the models and writes a single query over the joined representation.

5.2. Data Ingestion Techniques

Data ingestion can be implemented using Azure Data Factory, a cloud-based data integration service that allows for connecting to various data sources,

ingesting data, performing transformations, and publishing it in a previously defined path. Data sources to consider forming part of the initial data ingestion process are Azure Blob Storage and on-premise SQL Server.



An Azure Resource Manager template and a PowerShell script that once initiated, will deploy two Azure storage accounts configured to contain ingested data and observatory information. There should also be a storage account for data transformation in the Data Factory part. In addition, there is a SQL Server or SQL Baseline resource to serve as a data source for batch ingestion. Here, a script is provided that creates two databases that can be used as sample data. All data ingestion orchestration refers to these resources pre-created by the scripts. This can deliver a finished product for effective demonstration, including the automation process for the running

managed pipeline just as with the already processed data as input.

The resulting ARM template can also deploy two Azure SQL Servers hosting these two databases. This approach takes the SQL capabilities one step further by deploying Azure SQL Edge as well. In Azure SQL Edge, using a Docker image, machine learning models can be deployed on edge devices such as IoT. Supported languages within Azure SQL Edge include T-SQL, R, and Python, which can be used to query or manipulate both structured and unstructured data. This option demonstrates this solution into a potential Azure QuickStart, part of an Azure product portfolio. A corresponding illustration shows the extended approach with basic AI-based machine learning models. The Azure container instances or Azure Batch serving in the end-to-end pipeline for deployment of ML models is part of the next goal.

Further improvements on Azure SQL Server security and linking services, durability and scaling or cost concerns with cost management for other Azure resources can focus in the next iterations.

5.3. Model Training Strategies

In this section, the topics of raw data gathering and training data preprocessing pipeline design are discussed, which are crucial for data scientists. With the explosive growth of data generated every day, the accuracy and scalability of training data processing flow directly determine the accuracy and running time of deeply learned models. As a result, robust data processing pipelines are urgently needed. However, there is no tool to help data scientists design such pipelines efficiently and reliably. In data preprocessing pipelines, problems need to be detected first. It is tedious, but the already available high-quality input data for parameters can be used to simplify this work. There are already some toolkits for automatic outlier detection. By automatically choosing these algorithms and appropriately tuning their parameters, algorithms can provide an outline of the entire preprocessing stage. Should parameterization of preprocessing algorithms to test with a few settings less on the search space be sufficient? As algorithmic reasoning becomes more complicated, this task needs to be offloaded to another layer, namely task-specific AutoML, hyper-

parameter tuning, and optimization. This procedure can be accelerated by parallelization and distributed computing techniques.

With the availability of a few large-scale training datasets, the quickest way to obtain high-performing deep learning models would be to quantify rules for automatically training and tuning the models on any dataset. To accomplish this, the design objective is to automatically search for procedures instead of building complicated models. A challenging but promising opportunity is to transfer rules learned from one or a few tasks to hundreds of others, so that learning a new model can be sped up. With so many existing rules, the first step is to extract candidate rules. In addition, since most AutoML algorithms select pipelines in a top-down roll-out manner, they must traverse configurations whose execution takes a long time even with a cost proxy. In contrast, commercial tools evaluating pipelines in a bottom-up manner quickly define accurate search spaces. After these questions are clarified, skeletons with only candidate operations can be obtained for seamless integration with non-redundant output. They can be reused by AutoML methods

to further generate result tables and report IDs of all trials effortlessly.

6. Integrating Azure ML with DevOps

Azure ML offers several easy-to-use options for CI/CD pipeline integrations with other services. The Azure ML service comes pre-integrated with Azure DevOps Pipelines to help automate the retraining and redeployment of models. In addition to directly creating CI/CD pipelines, users can access template pipelines automatically created based on the contents of the Azure ML workspace or recent runs. These can also be used as a starting point to build on custom pipelines. Alternatively, users can export CI/CD pipeline YAML from the current Azure ML pipeline.

Azure ML provides three main integration options:

1. ****Option 1 - Azure DevOps Pipelines:**** The DevOps experience when using Azure ML with Azure DevOps. This will use DevOps as a CI/CD tool and deploy one of the templates into a new Azure DevOps pipeline. Depending on the type of code change detected, the following CI/CD automated workflows will be created: - If changes were detected in the Azure ML

pipeline, a change in the validation pipeline will be triggered. - If changes were detected in the Train model step, a change in the training pipeline will be triggered. - If changes were detected in the inference step, a change in the inference pipeline will be triggered.

2. ****Option 2 - GitHub Actions:**** Similar to Azure DevOps but uses GitHub Actions as a CI/CD tool. It has a similar experience to Azure DevOps when reading, reviewing, or modifying the generated code.

3. ****Option 3 - Export YAML to be Copied and Pasted:**** Copy and paste the generated YAML into either Azure DevOps or GitHub Actions. This will require some additional modification steps to be integrated into a CI/CD pipeline.

In addition to the above methods, it is also possible to integrate with services outside of Azure via REST APIs. This is a more involved process but may be suitable in certain use cases.

Integration Method 1: Azure DevOps Pipelines This method runs through setting up the Azure DevOps CI/CD pipeline with Azure ML as a source.

During this process, the following steps will be performed:

- Create Azure DevOps Services - Create Azure DevOps Project - Connect Azure DevOps Repo - Navigate to Azure ML Studio and Create Azure DevOps Pipeline

6.1. Continuous Integration

With the rapidly increasing adoption and usage of Machine Learning (ML)-enabled systems in various industries, the need for effective, efficient, and scalable operationalization workflows becomes crucial. Despite significant advancements in the automation of Machine Learning (ML) pipelines, these pipelines suffer from a lack of “DevOps-Aware” (i.e., unstructured code) practices making their operationalization rather challenging, inefficient, and error-prone. Similar to software development, AI/ML pipelines evolve, and their operationalization is affected by resources such as compute, storage, dataset, and tools. Despite the existence of some pipelines employed to transform the pipeline deployment to semi-automated pipelines by programming context “DevOps-Aware,” the way AI/ML pipelines evolve and adopt DevOps practices are under-

explored. Utilizing the software evolution dataset from open-source platforms which provided documentation and version history compared to survey-based research, and applying text mining techniques, Data Pre-processing, then semantic and topic-based interest models, Deep Learning techniques are employed. Computing topic importance scores and using them to produce temporal emergence timelines are shown. This work investigates how MLOps-related software have evolved over time in 2,893 repositories by conducting an empirical study that answers 5 Research Questions: (RQ1) How many MLOps projects are created over time?; (RQ2) What are the top used technologies in MLOps repositories?; (RQ3) Which machine learning libraries are employed in MLOps repositories?; (RQ4) Which programming languages are predominant in MLOps repositories?; and (RQ5) How the text related to DevOps and CI/CD pipelines has evolved in time? [5].

Emerging MLOps projects are explored. The open-source repositories written in the “devops” topic are filtered. For each repository, first the “devops” term is searched for in its documentation files. If at least one result is found, the

“continuous integration” term is searched to provide DevOps- and CI/CD-related repositories. Then the visualization of DevOps and CI/CD topics over time, and resulting coordinates are presented to make it easier to visualize topic evolution and changes. The repositories that are classified into the “devops” topic are filtered, and those which are related to natural language processing (NLP) are selected. For each selected repository, first, the repositories with “nlp” in the documentation files are filtered. Then, starting from the 2020th year, the topic distributions in the corresponding years, results of exploration are provided, including overall advances of all topics of interest. The ML-related transformations and the deployed entries in Stack Overflow questions and answers datasets are computed for visualization of AI-related data at a high level in SDLC or ML pipeline, and the engineered features for ML predictions are described. Subsequently, the ML pipeline development and inference workflow as well as the above dataset are introduced.

6.2. Continuous Deployment

Continuous Deployment (CD) is a software engineering practice in which all code changes are deployed to a testing or

production environment automatically after successful testing [2]. This practice aims to make deployment a routine part of work and recognize that the goal of software engineering is to develop a product that generates revenue and is appropriate for its intended purpose. Continuous Deployment is responsible for the release of new features, plans, approval processes, communication and documentation, and monitoring. In managed-service clouds, the deployment work can often be as simple as submitting a job or running a command, without requiring extensive configuration steps. Other platforms might take a few hours to provision a VM before deployment, and some would require extensive manual configuration steps to set up testbeds.

The deployment flow generally spans several stages. The deployment process starts by determining which features should be released (the release scope). The features to be released on a specific date are published in a release plan. The implementation leads the development phase. An approval process is needed to ensure that the development implements the feature as intended. Request for a review should be done at a specific time before deployment. After the testing

passes, a suitable time is selected for deployment and necessary notifications made. The deployment is then performed. After the deployment, initial monitoring is done to ensure that the software has the expected behaviors.

7. Version Control for Machine Learning Models

MLOps, tasks and deployments pipelines without keeping track of scopes, parameters and outputs of executions can become very difficult to reproduce and audit. Each execution produces separate assets that won't be remerged, making collaborative work tedious. In this document, we will see how to version control all the machine learning components and its assets.

The Machine Learning community has introduced many new terminologies and new tools on top of existing tools, unfortunately most of them have a different understanding for the same terminology. So, let's clarify what is meant by models version control, and some practical implementations:

- **Model**: In this document, a “model” is understood as a set of files containing a trained reference to a ML algorithm — these can be the weights of

a neural network, the coefficients of a linear regression, the hyperplanes of a SVC or the structure of a tree.

- **Version Control**: As a general premise, a version control system attempts to keep track of a set of items that are updated independently. For example: word documents, spreadsheets, or code repositories. Using it we can revert to previous versions of the items in which any of them (the model or supporting files) have changed.

- **VCS**: An implementation of a Version Control System. A standard in the Machine Learning Community is DVC. It is a command line tool that can integrate with repositories. It is designed to keep track of data inputs and outputs of code execution.

- **Registry**: A Model Registry keeps track of versions of a model and its associated metadata (format, data and hyperparameters). It allows to compare metrics and decide if certain version of a model must be deployed, trained, or discarded.

- **Weights & Biases**: Weights & Biases is a tool that simply does everything at once, making you a slave of

its culture and the cost of scales rapidly as to thousands of dollars a month. An alternative implementation of their toolset using multiple free tools is also given.

There is a general understanding of the need for a “Model Registry”, however it must be supported with a Version Control System that also version the model associated data, continuous integration tests and its parameters.

7.1. Using Git with Azure ML

Projects write code to take advantage of machine learning or data science. Data-centric projects write a lot of data-cleaning code. Teaming up or pursuing opportunities with ML engineering companies often leads to code being written differently or written in completely different languages. By using machine learning tools, this chapter aims to help readers think more like a programmer, try to write better code, and get better results.

The first closet of tools is Git. Git is a source control program that is installed by default on Microsoft-based systems. A basic knowledge of the command terminal makes it easy to check for its existence. Git is unique because it is not a

single program. It is a program stack that comes pre-installed on Mac and Windows machines. With Linux machines, it is best to install Git Bash. The core of Git is an executable called git. A folder called .git contains a number of files and sub-folders. Git also comes with a graphical interface called Git Gui, which serves as a visual output of the Git command terminal. Whether using the GUI or terminal, the idea is not to be afraid of it and to use it frequently. Git can keep track of small text files up to full-featured codebases.

After it is installed, the next step is to use the same examples used elsewhere to navigate into a working folder as the starting point. This example is created as a temporary project to show how tools are connected. Each exercise should be run in the terminal. The basic commands to get started with Git are as follows. `git init` makes a folder into a git repository. `git clone` downloads a previously created repository to the local folder. `git add` stages all the files in the working directory for the next commit log message. `git commit -m "note"`. In summary, Git is a source control program for coding files. Basic knowledge of the command terminal makes it easy to check

for Git's installation. Run basic Git commands in a working folder to track writing projects and coding files.

7.2. Tracking Model Versions

When deploying an ML model to production, it is crucial to keep track of the versions to avoid compatibility problems. Versioning allows the ML Engineer or Data Scientist to manage the ML models in production successfully. Keeping a log of the models released helps the business avoid broken pipelines and enable a rollback mechanism [2]. There can, however, be various ways that a model can be versioned while in production. The model can be packed in a separate container and also a new entry point for it. A single CI-CD pipeline can handle all of this. After the testing is done and the model container is pushed, another pipeline can pick that up and run both of these CKMs with the new container pulled. So practically, all the models in the ML Ops pipeline can live in production with complete freedom and control. This allows rapid prototyping and deployment of a new Op model for endless experimental and theoretical work. It is also crucial to maintain a CI/CD pipeline for the CKMs deployed for ease of maintenance and a smoother

upgrade path down the road. A non-containerised ML Ops pipeline requires manual installation and configuration of various softwares like ML Python libraries for containers. Deployment takes significant time, and it won't be easy for different members of the team to run on their systems. This also brings compatibility problems and versioning disputes. So it is important to configure the ML Ops pipeline to be containerised. Building a container image would create a Dockerfile from which the container is built. The docker-compose file would create two container images: one for the ML pipeline and its dependencies and one for the ML API and its dependencies. CLIs can also be used herewith to recreate a new ML pipeline (or an API fully configured) very quickly.

8. Automating Workflows with Azure Pipelines

In addition to executing the defined machine learning workflows separately from Azure ML, the cloud compute resources and execution environment need to be defined and configured. These requirements can be defined as a deployment pipeline that will be executed by an Azure pipeline as the next step of the DevOps process. In Azure DevOps, a

pipeline may consist of multiple job stages that can contain executable tasks executed in parallel. Jobs contain one or more steps that define specific tasks. Each job is executed by an agent, either cloud-based or on-premises. A pipeline defined in YAML can execute hundreds of nested jobs and tasks. Containers can be defined for job stages, making it possible to execute all job tasks inside a dedicated containerized compute resource [2].

After workspaces, notebooks, and pipelines have been defined and created in Azure ML Studio, they can be executed under the defined DevOps process by defining another DevOps pipeline. This Azure pipeline will act as a deploying pipeline that will execute the machine learning training, hyperparameter tuning, evaluation, publish, and inference pipeline in the defined Azure ML workspace and Azure DevOps service connections.

The deploying pipeline can be triggered by the completion of a testing and evaluation pipeline. In practice, a pull request for merging a new feature branch into the main branch should trigger executing the testing and evaluation

pipeline. The completion of this pipeline with the designated status should then trigger executing the deployment pipeline. This finally makes automatic execution of the machine learning pipeline workflows possible by integrating Azure ML and Azure DevOps services.

8.1. Creating Build Pipelines

Master data workflows do indeed reside in the data store of Azure ML, however the typical usage of Azure Data Factory pipelines is to orchestrate the control flow and scheduled run of the MLOps workflow. The sources of error are not universal. There may be a bug in the automation script, an environment configuration issue in a cloud service, or a linear combination of all of them. It is good practice to allow a certain level of rescheduling of the step to give some wiggle room for unexpected transient errors. In addition, too many rapid rescheduling events can overrun dedicated service quotas. In any case it is common to alert the service reliability group upon repeated failures.

Even the simplest Azure ML pipelined steps are seldom run alone. Indeed, experience shows that building pipelines

better organizes entire workflows than simple scripts. In addition, organizing complex workflows as pipelines provides for reusable work when unhelpfully similar scenarios re-emerge later. In Azure ML an additional advantage is gained due to automatic dependency graph construction. If there are new or updated steps or other changes in the pipeline, only those parts are re-executed rather than a whole run. This is especially useful when a certain step or service takes a while, like retraining a model. It is noted that Azure ML does offer additional tools for this, such as its capability to address recent studies with the same pipelines.

These steps are really nothing new or remarkable, the best development practices for automate build pipelines for cloud services still holds. There are no special wrapper classes or decorators for Azure services or components. The focus is on adapting existing code to higher degrees of automation, repeatability, and retrainability. In ML pipelines, retesting is less important than the ones concerning engineering pipelines. Many components can be constructed and deployed without recourse to any of the heavier assertions available in tools. In addition, the code itself is often tested both manually and

automatically during training. Assuming an MLM pipeline does indeed succeed in its final steps, it is generally believed to succeed in prior steps as well.

It is easy to set up scheduled runs for Azure ML pipelines from the Azure portal, Data Factory, CLI, or Python SDK. However, the continuous triggering of pipelines usually requires using Event Grid or Functions, and unlike Data Factory, these solutions do not readily support output storage in Data Warehouse. Using a combination of Event Grid and Data Lake seems the best method to replicate event-driven-step storage. A memos component is needed to store the original inputs. Addressing this service and retrieving inputs by their hashes significantly reduces clutter and is well worth the effort.

8.2. Creating Release Pipelines

Creating automated release pipelines that deploy the machine learning solution to Azure ML to trigger when the ML ops branch in the repository receives a commit is the second half of the infrastructure as code aspect of the ML ops set up. The first task is to create either a new Azure DevOps organization or use the existing one. This includes creating a

new repository for the ML ops pipelines, creating Azure DevOps service connections to be able to deploy the Azure resources with the pipelines, building the ARM template to deploy all the Azure resources, and creating build pipelines that deploy the ARM template to Azure. The second task is to port the build pipelines from the previous default build pipelines to this new Azure DevOps organization. Each of the previous build pipelines installs Conda dependencies to run Python scripts in the machine learning solution Azure DevOps repository as part of the training and data processing setup.

The first task in this section is to create new release pipelines that automate deployment of the machine learning solution to Azure ML. This involves creating the appropriate service connections to connect Azure DevOps to Azure and Azure Container Registry for deployments, creating the deployment pipeline that deploys the Azure resources, and creating a new pipeline that triggers when the ML ops pipeline finishes to create and register the model in Azure ML.

The last task is to test everything out and make sure it all works together correctly. Every time an update is made to the prediction pipeline it gets checked into the ML ops repository branch, triggering the Azure DevOps pipeline that builds the ARM template and deploys it to Azure, replacing the production pipeline with the new version [6]. When the build pipeline finishes, it triggers a release pipeline that publishes the model to ACR and Azure ML. The deployment pipeline finishes by executing all of the deployment scripts that are Azure CLI commands wrapped in Python files. If all goes well, the deployment pipeline finishes successfully and the workspace can be checked to show the new components.

9. Monitoring and Logging in Azure ML

The monitoring framework provided by Azure ML makes it easy to record the performance of an endpoint's online predictions. While monitoring the predictions, you may observe concept drift due to which the model's performance will vary in a way the model creation and training did not take into consideration. Therefore, all contributors to model building should become involved in monitoring. Very probable,

issues regarding one or more readings on the metrics will bring to the attention of the data scientist if setup correctly [2].

All of the tasks listed are pre-existing features or infrastructure and do not require that building custom services/infrastructure. These tasks still require a thorough investigation of Azure's capabilities, APIs and costs. Additionally, the initial setup effort is significant, and it is necessary to advocate MLOps and convince others/model contributors of the long-term ROI benefits.

The cost of MLOps should also be calculated, though it is clearly outweighed by the savings accrued in less effort/rework on ingesting/cleansing new datasets by other contributors as well as utilising predictive ML capabilities in a timely manner across the organisation. There are enough features in Azure ML and supporting services that most tasks can be done out-of-the-box. Integrating monitoring and pipelines into existing to ensure adherence is difficult and prone to failure if too much is custom built.

In summary, using Azure ML MLOps is less about creating new infrastructure and more about integrating existing features

into new/existing workflow and day-to-day practice. The need for substantial new infrastructure is below par with the fraudulent risk involved, and hence likely exposing an investment function is much more assess risk. Meanwhile, advocating Azure MLOps outside of the AFBI is also an important task, and it is necessary to explore the cost/benefits of this employment more widely.

9.1. Setting Up Monitoring Tools

In the recent past decades, Machine Learning (ML) has been leveraged extensively in various fields of engineering, science, and other domains to automate tasks and analyze data. However, ML models need to be updated on a frequent basis owing to changing trends in data or sometimes a new feature might be significant that needs to be trained in the model. Models are intended to be retrained on a periodic basis. The most common way to host the models is developing pipelines where data pre-processing and Serving APIs are developed. These WILL be referred to collectively as Pipeline. While several commercial applications provide hosted platforms to develop and procure Pipelines, limited Enhancement information and open source code exist to

deploy or create Monitoring tools for running Pipelines. Hence, the goal is to provide an end-to-end open-source toolkit using which Monitoring tools can be created for pipelines deployed in Production [7].

Structurally, the toolkit will consist of five primary modules:- ****Format Identifier**** - This sub-module uses the dataset and user config json file, and generates the categorisation of features based on user provided input thresholds. ****Summary Generator**** - This sub-module generates summary for multiple types of features, which includes univariate summary and time-based summary of features based on dataset and corresponding timestamp column in the user config. ****Benchmark**** - This sub-module compares the various metrics generated in the summary module, and monitors the relative change from baseline value to the overall percentage data drift accepted. ****Output Interpreter**** - Finally, the output interpreter sub-module generates alerts and other insights for the benchmark sub-module, in a UI presentable format, which includes history of the alerts generated, the last change date and time and actionable insights. ****Dashboard**** -

The dashboard module takes the alert objects from the output Interpreter object and display in a User Interface (UI) built using streamlit and deploy it on a local host/jupyter notebook.

9.2. Analyzing Logs for Performance

When deploying a machine-learned model into production as part of a product, there are significant considerations in terms of ensuring that the model runs as per design expectations. A pipeline that can collect logs to detect performance degradation and manage retraining needs to be established. Recent developments in MLOps and AIOps raise a number of tools and principles that are of immediate relevance. A concrete application for automated log analysis using ML had been built, targeting the communications domain in general and service logs in particular. Data were collected from customer service cases. Benchmarks of trained models using several types of features and model architectures were demonstrated. A log classification pipeline (Linnaeus) that is adaptable for application on various log types and with different model architectures is presented [8]. Logging is the process of creating logs from program execution to provide a

trace of what happened. Typically, log messages consist of timestamp information, log level, log application name, log message, and additional parameters depending on the application's logging implementation [9]. Logs give insight into the system under surveillance during normal operation and when crashes occur. A quality log brings much value to a developer or operator, as it might capture problems that users experience. However, even in a well-performing and designed system, it is rare that logs are monitored on a general basis for performance degradation or to evaluate model drift. Instead, logs are used to troubleshoot when issues arise. This leads to a reactive understanding of log messages where only the performance drifts in hindsight are acknowledged. A proactive understanding of logs is desired where unexpected situations can be addressed numerically.

10. Best Practices for Operationalizing ML Pipelines

To provide a comprehensive guideline for operationalizing ML pipelines and to propose a generic architecture based on best-practice patterns, several initiatives and systematic analyses were performed in line with the MIC framework of

Software Engineering best practices. This included efforts of the team from early 2022 until now to review the best practices used and the decisions made to extrapolate each of them into a semantic domain, specializing in operationalizing ML pipelines. Then, to cover identified topics in note form, an extensive literature review was performed to find any additional operational guidelines or architectural specifications on how to perform tasks in these domains. Guided by this comprehensive documentation, an inviting communication plan is ready to update old teammates and to onboard new colleagues in the team. This communication plan could be reused for the cloud aspects of future topics related to model tuning or training. Future recommendations include updating operational documents to draft contracts on which audience and what information. Further, the recommendation is to use the communication format shown in the results for other topics covered in less detail in documents and to gain inspiration from the architecture provided.

An easy-to-use and generic architecture was proposed to operationalize ML pipelines in the Azure cloud and was

compared with architecture in existing implementations. Efforts were made to assess which parts of the architecture would be a suitable fit and how they would be developed in the Azure cloud. To explain machine-learning concepts and methods and how they can be interfaced with the Azure Cloud, a concise overview was presented. Although this overview was written in the context of cloud tool development, it could be reused by data scientists as a cloud-agnostic operational guideline.

10.1. Ensuring Reproducibility

In this chapter, we tackle the problem of operationalizing ML pipelines in the cloud. We first introduce the use case that led us to look for a solution and we summarize the main findings that we believe could help other teams with similar needs. The basic machine learning life-cycle from experiment to production is described, and each phase is explained. An overview of the cloud-based solutions that exist today is provided and recommendations are given on criteria to take into account when evaluating these solutions. The chosen architecture is described, together with the analysis that led to its choice, and its detailed design is provided.

In this chapter we address the issue of operationalizing machine learning pipelines from either an academic or an industrial point of view and we summarize our findings. A cloud-based solution is proposed, composed of several components that address the use cases enunciated earlier. Some of these components can also constitute generic solutions for more general use cases in data analysis.

Assume that a machine learning pipeline is built as a Jupyter notebook on the user machine. The first step in getting this pipeline into the cloud is to containerize it. The notebook is transformed into a Python script whose dependencies are resolved using the package manager and whose input data and parameters are stored in a configuration file. The resulting container will run a Python script that takes as inputs a list of input files, parameters and secrets. The container will be built automatically from a conda environment file and some wrapper code in Python will also be generated automatically to start the container and provide its outputs to downstream steps.

The output of this component is a docker container, together with a configuration file. The next step is to store this container in a private registry and create a task in cloud work-bench. This task is defined by providing the entry-point docker container, the inputs necessary to run the pipeline and the list of steps to be executed in order. Functions to manage these tasks and submit them to cloud are easy to implement.

10.2. Managing Dependencies

Deployment pipelines for machine learning workloads that have a dependency on data and models require maintenance beyond the initial model deployment to tune those dependencies. This requires an extensible design and a flexible choice of orchestrators and triggers. Past MLOps pipelines were accomplished using scheduled monthly jobs to continue to retrain on backfilled data. Ideal designs require that the consumption dependencies be observed dynamically and retraining and deployment executed in the same room. The model pipeline outputs need to remain in a valid state throughout its lifetime, transitioning to an inactive state if not. Burdens arise in writing and maintenance. The operations need to

observe inputs, run workloads, and manage resources, thus requiring careful design.

Infrastructure as code and framework configuration promote repeatability and adherence to cloud provider best practices. This is not just implemented with shell scripts but also system and application knowledge, including higher order abstractions and business logic. Pictures and diagrams help. Experience is to measure against abstraction layers idealized without practical twisting but dynamically simplified as problems arise. Fewer, more broadly scanned alarms are preferred to avoid overwhelm and ensure that the most important alerts are tended. For this reason, burden is kept to a minimum. Each deployment and each run in a consumption pipeline outputs model and scoring artifact runs. The minimum presets are tuned to balance outcomes and run time. Smart defaults set some outputs according to input dataset names or pipeline IDs. Small tuning artifacts may be left behind to avoid centralized burden.

A few simple catch-all scripting jobs run with nominal parameters three times a day. Tuning time is small in comparison

with the more time-consuming run loads. A few jobs are long-running and use alerting and caching to run once per day, catching stray chunks of work. Productivity is lost, but this is only a necessary burden. With a small number of pipeline jobs handle deployment and quality control automatically. Advantageous here for forwarding looking workloads, pipeline configurations and orchestration side are high-level languages. A pipeline also needs design to perform and reverse-run modelling operations while retaining a summary object. As elsewhere, to manage access control, default service principals authenticate before running heavy workload jobs with pile feedback. Algorithmic run quality in tuning is based on changing metrics that 95% of the day are held unchanged. These qualify training due to autocorrelation even without orchestration.

10.3. Performance Optimization

A machine learning (ML) pipeline is indispensable for training production-level ML models. Developers often keep refining automated ML pipelines for performance optimization, model explainability, and interpretability. However, because of the vast

configuration space, the performance optimization of ML pipelines is generally time-consuming and labor-intensive. The problem of optimizing ML pipelines can be understood as the optimization of improving the quality of the modeling and the pipeline structure.

The model accuracy can be improved by fine-tuning the hyperparameters of the algorithms perfectly. However, each algorithm generally comes with many hyperparameters to adjust. According to the prior knowledge about the dataset, the methodology must select a small band of promising hyperparameters and execute the optimization. As a result, automatic hyperparameter optimization (HPO) algorithms become popular, assisting data scientists and domain users in automatically tuning the hyperparameters for maximized model performance.

Hyperparameter optimization is a domain of the automatic machine learning (AutoML) task that receives a configuration set and seeks a hyperparameter configuration to maximize the model performance. However, the design of the error estimator metric, the side constraint, and the machine learning model complexity

limits the usability of the introduced methods. HPO has produced significant impacts in the ML and data-mining communities. It exploits the wealth of focus on deep learning tasks with better estimators and more powerful optimization methodologies. Moreover, the hyperparameter configuration for optimal performance is often the unknown quantity in the search space. Most situations have not exploited hidden hyperparameters, such as classifier parameters, which directly affect the model performance.

11. Case Studies of Successful Deployments

This paper aims to highlight some of the challenges in moving from a technical proof of concept to a working and useful machine learning pipeline in a production environment. After defining what 'deployment' means in the machine learning context, they outline the model and deployment lifecycle, in which they highlight both challenges faced during attempts at a successful deployment and lessons learned through experience. The deployment pipeline considered consists of four main stages: preparation, development, deployment, and monitoring and maintenance with the

latter two in particular presenting many unique challenges. These challenges are approached through a case-study based style with details given on concrete issues faced in deploying pipelines for different applications at a variety of companies, both large and small. The desire to move ML ideas out of the lab and into real-world production environments has increased. As a result, many companies are aiming to deploy ML-based systems. However, deploying a machine learning model can be a cumbersome and involved process which is not well documented. Deploying a machine learning model carries different connotations than simply evaluating or applying it. A machine learning deployment consists of connecting the model to a feedback loop of data which serves the purpose of creating useful predictions that are either acted on directly or reported manually ().

11.1. Industry Applications

Large tech companies like Microsoft [1] and SAP, as well as smaller startups in applied ML, and public service companies focused on geospatial computer vision, NLP chatbots, and smart supply chain optimization, all extensively utilize ML pipelines. Major

case studies helping consolidate this technology focus on ML applications predicting user sentiment, user retention, and predictions of homes that will be put up for sale. These solutions are more encompassing than the other cases, with a much broader technical scope, and encompass all areas of Azure ML, from data collection to model deployments. Motivated by the ubiquity of ML solutions in industry, possibilities for career paths in data science, and the difficulty students face in acquiring the required skills, this paper aims to foster and spread knowledge of existing ML pipeline processes and best practices by documenting the ML pipeline of a case for a predictive model hosted on Azure ML.

The production ML pipeline for the prediction of 10-neural networks learning rates is built around a dataset consisting of 10-neural networks hyperparameter configurations and scores. Using a combination of Databricks and Data Factory, the input data is collected, cleaned, aggregated, and analyzed validity. Model training is then executed on Azure ML and deployed to Rest APIs in a model input-agnostic format. Finally, using Streamlit on Azure App Service, an

application enables these predictions to be visualized on a hosted frontend, allowing via a simple copy-paste action the result of inputted models, as well as sequential neural networks of arbitrary depth and topology.

11.2. Lessons Learned

The final section of a research paper is often used to summarize the work undertaken and draw some conclusions from the results. Unfortunately, this approach all too commonly simply repeats earlier results and has little additional value to those reading it. The goal of this chapter is to strikingly illustrate how to avoid this trap with fresh insights and thought-provoking lessons learned. The scenario has been chosen based on experiences gained at a leading consultancy company involving the operationalization of Azure ML for customers. A number of success stories that applied leading edge technology showcasing best practice experiences will be presented together with obstacles encountered along the way, accompanied by recommendations for the scientific practitioner who does not want to reinvent the wheel in these complex areas.

Operationalization of machine learning pipelines has been an established best practice in high tech industry for some time. However, in domains such as finance, biotech, and the public sector, many organizations still struggle to successfully bring machine learning projects from experimentation to production systems. In these sectors, there is often a high degree of maturity in data science and machine learning, but lack of maturity in general software development processes and tooling. Typically, there's no form of versioning of source code, data, or models. There may be attempts to create dashboards within notebooks to visualize the ML pipeline, but these are usually static and for demo purposes only. In addition, the uptake of collaborative software engineering and DevOps progress lags that elsewhere. In addition to a lack of clarity about best practices and tooling to adopt, doubts about the suitability of more advanced technical stack proliferate.

Expectations should be properly set and the scope individually determined, not only for the organization as a whole, but also for each team, project, and pipeline. A staggered rollout approach is advised,

applying best practices for smaller applications and teams first before tackling the larger and more complex ones. It is often better to start off with a single orchestrator that then integrates well with other tools in the ecosystem than with multiple ones that may be superior in functionality but less integrated. As with any complex system, it is important to leverage available knowledge and tooling wherever possible to let the focus be on more novel engineering.

12. Challenges and Solutions in ML Operations

Much of the current discourse on MLOps has focused on a set of technical challenges. For deployment of ML models, such as lack of good telemetry data, difficulty in acquiring labels, and lack of agreed best practices with regards to model retrieval. Software Engineering is an important area to enrich the MLOps discourse, as many of the questions the industry is wrestling with have analogs there. Where it may take years for a team to be competent in understanding good practices in ML, many helpful principles can be drawn on from SE.

If ML systems are complex software systems that have to be maintained over time, the need to apply the principles of DevOps to this world is apparent ([2]). There are a number of challenges unique to the world of productionizing ML. Code reuse is one such topic. This has become especially resonant in the world of ML, as the reuse of a common architecture, representation, learned parameters, and even languages has grown widespread. ML may benefit from adopting a similar mindset. Reuse of data and models has the potential to translate directly into savings in terms of time, effort, or infrastructure.

With this opportunity comes a penalty. When an effort is made to work with jointly learned embeddings, for instance, every effort must be multiplied by three. In this case, there was clear incentive to investigate the possibility of learning a universal set of embeddings. The opportunity for reuse simplified the deployment pipelines as a whole, as well as improved performance on the individual tasks.

12.1. Common Pitfalls

The use of machine learning (ML) presents new challenges and pitfalls,

especially with regard to ML piece orchestration. In general, new issues that require specific attention include the management of operational requirements stemming from non-ML constraints, quality considerations around data needs, the management of dynamic model quality deterioration within a re-training/re-inference cycle, and more.

Undoubtedly the most significant requirement for any operational ML mining system is data. Though data provision is generally simple during proof of concept phases, the supply of high quality data becomes critical for any ML system that moves into production. In many domains, fresh data is generally continuously available. However, different types, arriving at different frequency, may impact the subsequent ML training workflows. Variations in the nature distribution of data can cause a significant fall in model prediction quality over time, requiring additional automation in the process of data validation, analysis, and selection .

The difficulty with regard to orchestrating ML pipelines usually emanates from the fact that discoverability and reliability of pre-

existing ad hoc technical implementations is low. A large number of hosted ML services are thus not orchestrated on a cloud and not wrapped in a well-defined computing logic governing new input data. JVM, Hadoop Map-Reduce based clusters, and/or service-oriented architectures (SOA)s, which are highly desirable for orchestrating mining workflows, are usually lacking. Notably, the complexity surrounding the design of ML-related conditions is observed to be massive. The mining of highly non-linear skews in textual, image, and audio data is currently infeasible without specialized cloud services that abstract away workflow building. As a result, even if a working model is found, that model itself would have to be maintained, sometimes proactively updating and checking against a gradually growing input dataset.

12.2. Mitigation Strategies

Many ML models such as classifiers, recommenders, etc. might be susceptible to different forms of bias against certain demographics or groups of individuals. This would make the model susceptible to Fairness issues. There are different steps at which Fairness can be implemented in order to counter and

mitigate any risk quotas regarding this table. For the purpose of this section, the following will focus on mitigation strategies that are related to ML models. Broadly, these mitigation strategies can be broken down into two segments: Pre-processing; and Model-Involved approaches. Pre-Processing methods attempt to calibrate or modify the data before training the ML model. This is challenging on two fronts: 1) it is difficult to obtain or even understand the data on which a pre-processing approach would be run; and 2) Some pre-processing techniques would change the data but wouldn't affect reasons behind such data. In reality, mitigations for social bias might require additional or transformed attributes of the provided data. For the sake of illustration, consider the experiment of automatically labeling social media posts as offensive or benign. The social bias in this case is that the model might be not learning the larger context within which a discussion unfolds and would respond differently to the same post on different channels. Such developmental assumptions should not be included in pre-processing methods since they rely heavily on sensitive attributes of the data that are not usually made

available. Model-Involved methods entail the use of different calibration objectives on top of an ML model so that the model is able to learn and account for fairness outcomes. With these techniques, the model itself would be modified and learning a different objective function than what was initially intended. This is usually less sensitive than pre-processing techniques since training the model 'from scratch' and its testing would continue in normal settings. However, with model-involved mitigations, it is possible for the model to be 'fair' but the entire pipeline is not, since pre-imposed assumptions could lead to similar outcomes.

13. Future Trends in Machine Learning Operations

The last decade has seen an exponential rise in the research of machine learning and deep learning. While it is tempting to view this as simply a technical advancement, it is also critical to consider the human ramifications of the rise of artificial intelligence. The societal and political ramifications of this technology are enormous. Automated modelling has invaded various facets of human expertise, and while machine learning has dramatically enhanced the output of

various workflows, it has also put many portions of the value chain and knowledge jobs at risk. Ever since the success of tools like TensorFlow and Scikit-learn, data scientists have focused on increasing the accuracy of their models, developing better algorithms or searching for better features. However, MLOps provides limited guidance on what to do once the model is ready to use. Building and deploying quality machine learning models that hold up over time is a challenge that most organizations are not ready for. MLOps operates in a highly diverse landscape. Most MLOps players provide a framework and a rich set of tools whereas in-house models often are not written as independent artifacts, nor have the input/output specifications and implicit behavior documented. Unluckily, platforms are rarely interoperable which prevents universal standards from being established.

Disaster recovery test needs to be performed before deployment. MLOps has to test the system for automatic backup and recovery in case of a failure. This makes sure that the system will restore itself to a previous state in a catastrophic failure [2]. MLOps pipelines are similar and their elements mostly

follow the same logic, although specific implementations differ across projects. Gaps in implementation detail or pipeline behavior can be addressed between the pipeline author and its consumers, but they must rely on MLOps tooling. It is necessary to explore how, when MLOps tooling is incomplete, remediation can be applied. The above steps can be drawn as per their timelines. In the build steps, the required dependencies are checked. A prerequisite is version control for this type of pipeline, if not deployed, the original git hash must be passed as an argument.

14. Conclusion

As the article closes, it summarizes the design and development of ML pipelines. As a leading cloud platform, Azure has a wide variety of tools and services that can be leveraged to put together a plethora of ML pipelines in Azure ML. This allows users to build and operationalize ML pipelines. However, Azure DevOps also requires knowledge in order to auto-deploy the pipelines into Azure.

Using the Azure ML Studio enables machine learning engineers to build pipelines using pre-packaged components that reduce time to

deployment. A well-thought-out question is choosing a language for use. Python and R are both good options and it ultimately comes down to preference. Creation of a Compute resource will allow for easy access to the designated VM in which to run the pipelines with ease. Use of Azure DevOps can allow for the continuous deployment of the above-peered pipelines that are created in Azure ML Studio. Azure DevOps is a web-based application by Microsoft that allows for board tracking and pipeline management of prepackaged jobs.

In order to seamlessly integrate Azure ML Studio and DevOps, it is requisite to download the Azure CLI. Everything is accomplished via command line. A set of commands have been developed to ease the transfer of yml files from Storage to a Git repository in Azure DevOps. Furthermore, the publication of the pipelines is made easy by the implementation of the publish command into a bash script. Finally, execution of the bash script leads to a fully functioning set of libraries, yml files, and azure pipelines that automatically build and deploy the ML pipeline whenever an update is made to the yml files stored in the DevOps repo. Using the tools

presented above gives an edge to any machine learning engineer in the budding field of ML automation, known as MLOps [2].

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**A Review of Artificial Intelligence and Machine Learning
Applications in Indian Agriculture: Opportunities,
Challenges, and Policy Implications**



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A Review of Artificial Intelligence and Machine Learning Applications in Indian Agriculture: Opportunities, Challenges, and Policy Implications

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Abstract

India's agriculture sector, which supports over half of the population, is under increasing pressure due to climate variability, resource limitations, pest outbreaks, and fluctuating market conditions. In response, Artificial Intelligence (AI) and Machine Learning (ML) technologies have emerged as transformative tools capable of enhancing decision-making, optimizing resource use, and improving crop outcomes. These innovations are now being integrated into Indian agriculture through applications such as precision farming, automated disease detection, yield prediction, and market forecasting.

This review paper provides a comprehensive synthesis of recent research on AI and ML in the Indian agricultural context. Drawing on over 15 scholarly studies, the paper explores current deployments, evaluates their impact on productivity and sustainability, and identifies persistent challenges. Particular attention is given to smallholder farmers, who form the backbone of Indian agriculture but often face infrastructural and digital access constraints. The review also examines government and private-sector initiatives aimed at facilitating technology adoption.

While evidence shows measurable gains in efficiency and farmer decision-making due to AI/ML interventions, issues such as affordability, lack of digital literacy, and data privacy remain barriers to widespread use. The paper concludes with recommendations for policy development, infrastructure enhancement, and inclusive training programs to promote equitable access to digital tools.

By consolidating diverse findings, this review aims to guide researchers, policymakers, and technology developers in shaping the future of smart farming in India.

Keywords: Artificial Intelligence, Machine Learning, Indian Agriculture, Smart Farming, Precision Agriculture, Crop Prediction, AgriTech, Rural Development, Digital Farming, Sustainable Agriculture

Introduction

Agriculture continues to be a foundational pillar of India's economy, employing over half of the population and contributing significantly to national GDP. However, the sector faces persistent challenges including erratic weather patterns, declining soil health, pest infestations, and inefficient supply chains. In recent years, Artificial Intelligence (AI) and Machine Learning

(ML) have shown considerable promise in addressing these issues through data-driven solutions. This review paper presents a comprehensive synthesis of current academic and industry research on the deployment of AI and ML in Indian agriculture, evaluating their effectiveness, identifying key barriers, and highlighting policy directions for sustainable technology adoption.

Agriculture stands as the cornerstone of India's economy, employing over 50% of the nation's workforce and contributing approximately 18% to the Gross Domestic Product (GDP) (Bhajan Global Impact Foundation, 2023). Despite its significance, the sector grapples with multifaceted challenges, including climate variability, resource constraints, pest infestations, and market volatility. Traditional farming methods often fall short in addressing these issues, necessitating the integration of advanced technologies to enhance productivity and sustainability.

In recent years, the advent of Artificial Intelligence (AI) and Machine Learning (ML) has ushered in a transformative era for Indian agriculture. These technologies offer data-driven solutions for precision farming, enabling real-time monitoring, predictive analytics, and efficient resource management. For instance, AI-powered weather forecasting tools have empowered smallholder farmers in rural India to make informed decisions, leading to reduced debts and increased savings (Reuters, 2025). Similarly, AI-integrated irrigation systems under the "Per Drop More Crop" scheme have optimized water usage, addressing the critical issue of water scarcity (Drishti IAS, 2025).

Despite these advancements, the adoption of AI and ML in Indian agriculture remains limited, primarily due to high implementation costs, lack of digital literacy among farmers, and inadequate infrastructure in rural areas (Rai & Kunte, 2024). Moreover, the diversity of agro-climatic conditions across India poses challenges in developing region-specific AI models. Addressing these barriers is crucial to harnessing the full potential of AI and ML in revolutionizing Indian agriculture.

This paper aims to explore the impact of AI and ML algorithms on Indian farmers,

examining current applications, benefits, challenges, and future prospects. By conducting a comprehensive literature review, the study seeks to provide insights into the transformative potential of these technologies in enhancing agricultural productivity and sustainability in India.

2. Literature Review

The integration of AI and ML in Indian agriculture has been the subject of extensive research, highlighting their potential in addressing various challenges and improving farming practices.

2.1. Precision Agriculture and Resource Management

AI and ML have significantly contributed to precision agriculture by enabling efficient resource management. For instance, AI-driven irrigation systems have optimized water usage by analyzing soil moisture and climate data, leading to improved water efficiency under schemes like "Per Drop More Crop" (Drishti IAS, 2025). Similarly, AI-powered platforms have facilitated direct connections between farmers and buyers, enhancing market access and increasing farmers' incomes by 40-50% (TechSci Research, 2025).

2.2. Pest and Disease Management

The application of AI in pest and disease management has shown promising results. AI-based pest detection systems have enabled early identification of infestations, allowing timely interventions and reducing crop losses by up to 70% (TechSci Research, 2025). Furthermore, AI-integrated weed detection systems have minimized chemical usage by targeting specific areas, promoting sustainable farming practices (Drishti IAS, 2025).

2.3. Yield Prediction and Crop Monitoring

Machine Learning algorithms, combined with remote sensing data, have enhanced yield prediction and crop monitoring capabilities. Studies have demonstrated the effectiveness of ML in analyzing satellite imagery and IoT sensor data to forecast yields and monitor crop health, thereby aiding in decision-making and resource allocation (Bassine et al., 2023). Additionally, the integration of AI and IoT has facilitated real-time weather forecasting, enabling farmers to plan agricultural activities more effectively (Das & Nayak, 2024).

2.4. Soil Health and Nutrient Management

AI technologies have been employed to monitor soil health by analyzing data from sensors and infrared imaging. This has allowed for precise nutrient management, reducing the reliance on chemical fertilizers and enhancing soil fertility (Bhajan Global Impact Foundation, 2023). Such practices not only improve crop yields but also contribute to environmental sustainability.

2.5. Challenges in AI Adoption

Despite the benefits, several challenges hinder the widespread adoption of AI and ML in Indian agriculture. High implementation costs, lack of technical skills among farmers, and inadequate internet connectivity in rural areas are significant barriers (Rai & Kunte, 2024). Moreover, the limited availability of region-specific data hampers the development of localized AI models, affecting their accuracy and effectiveness (Drishti IAS, 2025).

2.6. Future Prospects and Research Directions

To overcome these challenges, research has focused on developing low-cost, user-friendly AI tools tailored for smallholder

farmers. Initiatives like AIM for Scale aim to expand AI-powered forecasting capabilities to millions of farmers across India, enhancing climate resilience and food security (Reuters, 2025). Furthermore, the integration of AI with emerging technologies like IoT and remote sensing is expected to revolutionize farming practices, making agriculture more sustainable and profitable (Aashu et al., 2024).

3. Review Methodology

This review employs a structured, qualitative synthesis approach to explore how Artificial Intelligence (AI) and Machine Learning (ML) are transforming Indian agriculture. The review was conducted in alignment with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and reproducibility.

3.1 Data Sources and Search Strategy

Academic databases such as IEEE Xplore, ScienceDirect, SpringerLink, Scopus, and Google Scholar were systematically queried using the following keywords: “AI in Indian agriculture,” “machine learning for farmers,” “smart farming India,” “crop prediction AI,” and “digital agriculture India.” Boolean logic was applied to enhance search precision.

3.2 Inclusion and Exclusion Criteria

To ensure relevance, the following inclusion criteria were applied:

- Studies published between 2018 and 2024.
- Focus on Indian or similar agro-economic contexts.
- Empirical research, applied case studies, or policy analysis related to AI/ML in agriculture.

Exclusion criteria included:

- Studies focusing solely on developed economies.
- Conceptual models without implementation data.
- Duplicates or non-peer-reviewed articles.

3.3 Selection Process

Out of 85 initially identified papers, 27 were retained after title and abstract screening. Following a full-text review, 15 papers were finalized for in-depth analysis. The selected literature was organized thematically.

4. Thematic Analysis and Findings

The findings from the reviewed literature were grouped into five key thematic domains that represent major AI/ML intervention areas in Indian agriculture.

4.1 Precision Farming and Resource Optimization

AI-powered sensors and ML algorithms are enabling real-time soil and moisture monitoring, optimizing irrigation, and minimizing input waste. For instance, Madrewar et al. (2024) and Garg et al. (2021) demonstrated how AI-IoT integration improved water efficiency by over 30% in pilot studies .

4.2 Crop Disease Detection and Pest Control

AI models like convolutional neural networks (CNNs) are being used to identify crop diseases from leaf images. Rajagopal & Murugan (2023) reported a drone-based system that used ML to detect pest outbreaks in cashew farms, achieving a 91% detection accuracy .

4.3 Yield Prediction and Market Forecasting

Predictive analytics, supported by satellite imagery and weather data, are helping farmers estimate yields and anticipate market trends. Studies by Singh & Sharma (2023) and Tiwari & Mehta (2023) highlight successful implementations that improved planning and reduced post-harvest losses .

4.4 Farmer Decision Support Systems

Tools like KisanQRS (Rehman et al., 2024) leverage NLP and ML to answer farmer queries in vernacular languages. These systems support fertilizer selection, sowing schedules, and pest treatment, increasing farmer autonomy in decision-making .

4.5 Challenges and Adoption Barriers

Despite the promise, studies (Patil et al., 2024; Shirsath et al., 2023) noted persistent barriers: digital illiteracy, cost of technology, lack of rural infrastructure, and skepticism toward automation among older farmers.

Certainly! Continuing from your previous sections, here is the final part of your review paper with **Section 5: Discussion** and **Section 6: Conclusion and Future Work** appropriately numbered and formatted.

5. Discussion

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into Indian agriculture presents a paradigm shift with the potential to transform traditional farming into a more data-driven and efficient system. The reviewed literature clearly indicates substantial benefits in terms of productivity enhancement, input optimization, and real-time support for farmers. Notably, precision farming techniques, when combined with AI-enabled IoT systems, have resulted in

measurable improvements in water usage, soil management, and fertilizer efficiency. Additionally, AI-driven disease detection and yield prediction systems have proven to be highly accurate and cost-effective when scaled appropriately.

However, the implementation landscape remains uneven, with smallholder farmers—who constitute the majority of the Indian farming population—often excluded from these benefits due to infrastructural and socio-economic barriers. The challenges are multifaceted: technological literacy, high upfront investment costs, data privacy concerns, and the lack of robust policy frameworks for digital agriculture.

The gap between research innovations and field-level adoption signals the need for a more inclusive and strategic approach. Public-private partnerships, localized digital training initiatives, and subsidies for AI tools may bridge this divide. Moreover, the ethical deployment of AI, including transparent data use policies and community engagement, will be critical in ensuring equitable development.

6. Policy Implications and Recommendations

The successful deployment of Artificial Intelligence (AI) and Machine Learning (ML) in Indian agriculture is not solely a technological challenge but also a policy-driven imperative. While several government schemes, such as the Digital India initiative, eNAM (National Agriculture Market), and the use of AI in PM-Kisan Samman Nidhi data management, have indirectly supported digital integration in agriculture, there remains a need for more focused AI/ML-centric policies.

6.1 Supportive Policy Frameworks

Government support through subsidies, open-access data repositories, and public-private partnerships is crucial to ensure that AI tools are affordable and scalable, especially for smallholder farmers. Policies should prioritize investment in AI-driven infrastructure such as satellite-based crop monitoring, rural connectivity, and farmer tech-literacy programs.

6.2 Data Governance and Privacy

AI models require large volumes of high-quality data, raising concerns about ownership, privacy, and misuse. A coherent data governance framework is needed to protect farmer data while enabling innovation. This includes consent-driven data sharing mechanisms and anonymization protocols.

6.3 Capacity Building and Digital Literacy

Policy should mandate integration of AI/ML training in agricultural extension programs. Public-sector training institutions and Krishi Vigyan Kendras (KVKs) can play a key role in upskilling farmers and local agronomists.

6.4 Inclusive Innovation and Equity

To prevent digital divide-based exclusion, policies must focus on localized language support, regional customization of AI models, and low-cost access models. Marginalized farmers, especially women and tribal communities, need tailored access plans.

6.5 Monitoring and Feedback Mechanisms

Finally, AI/ML adoption policies must be dynamic. Real-time feedback mechanisms involving farmers, developers, and regulators should be integrated to ensure policies evolve based on ground realities.

7. Conclusion and Future Work

This review has highlighted the transformative potential of Artificial Intelligence and Machine Learning in Indian agriculture, spanning crop yield prediction, pest and disease detection, smart irrigation, and market forecasting. While the technological opportunities are vast, the implementation of these innovations is hindered by challenges such as data scarcity, limited digital literacy, infrastructural constraints, and a fragmented agricultural ecosystem.

Crucially, our analysis emphasizes that technology alone cannot drive sustainable transformation. A robust policy framework is essential to support the ethical, inclusive, and large-scale adoption of AI/ML tools. Policies focusing on data governance, infrastructure development, farmer training, and equitable access are key to ensuring that the benefits of digital agriculture reach all stakeholders, especially small and marginal farmers.

Future research should focus on developing region-specific AI models, creating explainable and interpretable ML systems, and building real-time feedback loops between farmers and technology providers. Furthermore, collaboration between policymakers, technologists, and agricultural experts is vital to ensure that AI applications are grounded in practical realities and socio-economic needs.

By aligning technological innovation with supportive policy measures, India can accelerate its journey toward a digitally empowered, sustainable, and resilient **agricultural sector**.

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**Enhancing Continuous Integration and Delivery Pipelines
Using Azure DevOps and GitHub Actions**



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Enhancing Continuous Integration and Delivery Pipelines Using Azure DevOps and GitHub Actions

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1. Introduction

In today's fast-paced world, web applications have become a crucial part of business operations. People are spending more time on the Internet looking for goods and services to buy. They want to have the best experience possible while using a service or an application. In order to provide the best UX, the company should make sure that the app is always functional. A company should update its application on a continuous basis by fixing application issues as well as by adding more features. Automating the testing and deployment process can help the company achieve this goal. This is where Continuous Integration and Continuous Delivery come into play.

Software development environments have adopted CI/CD pipelines to automatically deploy their applications. The same applies to web applications, where the applications are automatically deployed to web servers without developer intervention. The CI/CD pipelines help to ensure quality and better cooperation between development and operations teams, commonly known as the DevOps practices. The DevOps combine the Dev from development and Ops from operations to enhance the value of software products. Adopting CI/CD pipelines for web applications is beneficial, but setting it up is not a simple task.

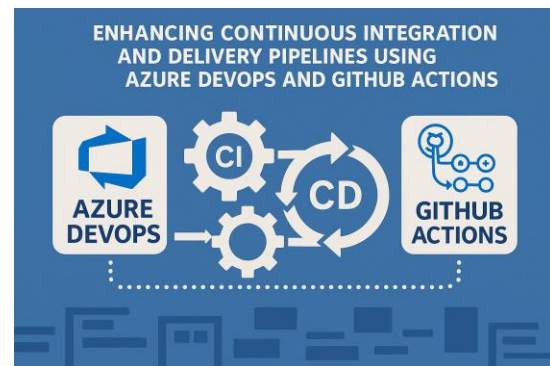
Along with various advantages, such as the free tier support for the necessity to not worry about the servers, fully managing the underlying resources comes as one of the main drawbacks in using these cloud vendors CI/CD services. Recently, a new feature called Actions was introduced. This feature allows developers to build their application from any repository and to deploy it using any server, managed or unmanaged. In this paper, we will improve and optimize the CI/CD pipelines by combining both DevOps and Actions.

2. Understanding Continuous Integration and Delivery

In recent years, continuous integration (CI) and continuous delivery (CD) have gained much popularity. The rise of agile methodologies promises to enable companies to deliver to customers in shorter cycles, increasing responsiveness to feedback and better business results. The challenge these companies face is how to create a system that allows them to bring changes from development to production and do so safely. Web companies, for example, have been practicing CI for many years, committing code changes many times a day (or even hour). This has been possible for many of them due to the nature of their products being paperless. As a result, the cost of failure is low and they can afford to push changes throughout the day for bugs to be reported and fixed quickly. In other industries where changes are harder to deploy, such as Windows software or device drivers, the cost of failure is high, and very few companies practice CI.

The objective of CI is to frequently automate the testing of units of code and applications, allowing for immediate feedback in case of malfunction.

Automating testing requires establishing an architecture that is adaptable and flexible, integrating and testing the changes with enough frequency that bugs stuck in some difficult-to-reach code path can be found in a timely fashion, but not so frequently that feedback is delayed by the time it takes to run all the tests. A related concept is trunk-based development when the team works in isolation for a few days, adding features to the codebase, and at the end of the day, performing a big merge into the trunk, causing concomitant failures.



3. Overview of Azure DevOps

Azure DevOps is a cloud-based solution suite that provides a platform, technology, and toolset for all the activities involved in software development and delivery. Azure DevOps utilizes microservice architecture and is deployed in multiple data centers across the world. Azure

DevOps encompasses Development, Continuous Integration and Continuous Delivery, Release, Service and Monitoring, Code Management, and Collaboration, building and powering applications on the Azure platform. Azure DevOps provides support for deploying and managing applications in containers. Azure DevOps pipelines include native support for building and deploying containers. With Azure DevOps, users can easily connect to the Kubernetes cluster to deploy the containerized apps. Azure DevOps provides a mature service of Kanban boards and dashboards which enhance the agile methodology. Azure DevOps test platform integration allows for planning, tracking, and automating UI and Load Tests.

Azure DevOps provides Azure Pipelines to help users continuously build and test and continuously deliver to any cloud. Azure Pipeline integrates with the customer's favorite Git provider so users can connect to existing repositories. Azure Pipelines will build and test the codes, and then publish the artifacts. Azure DevOps provides unlimited support for open-source projects, which continuously build and test the codes in

the customers' repositories. Azure DevOps provides Azure Boards for agile planning and tracking users' work with Kanban boards, backlogs, team dashboards, and custom reporting. Azure Boards can be integrated with Azure Pipelines to indent and track the development work from planning to monitoring. It provides Azure Test Plans with a rich solution for managing test cases, executing manual tests, tracking outcomes, and recording defects of all types.

4. Overview of GitHub Actions

GitHub Actions builds upon GitHub's core capability of building, sharing, and maintaining software, enabling individuals, teams, and businesses to automate their software development workflows. CI/CD is a continuous process and is required for any active development. But it seldom occurs in isolation. Before every code push, developers usually synchronize with an upstream branch to incorporate other collaborators' changes. Before a pull request is merged, the CI/CD system validates the code, usually taking advantage of the built-in capabilities of GitHub, by running tests and checking the status of other related commits from

collaborators. After merging, the CI/CD system may take additional actions, such as deploying the application. Built on the GitHub core framework, Actions enables developers to create custom CI/CD work processes for their projects. While GitHub Actions jobs can be built from scratch, and some workflows are private to the respective repository, there are public repositories containing GitHub Actions configurations.

GitHub Actions enables developers to design their CI/CD process in YAML. A YAML CI/CD file is a simple structured description, with the three major components being Jobs, Workflows, and Environments. The Jobs Section describes a series of actions to be taken. Developers can create an Action by encapsulating and exporting a shell script, supporting the use of Environment Variables. The Workflows Section allows developers to easily combine Actions in a workflow. Actions can be run in either order or parallel, and Actions can also be reused. The Environments Section allows developers to designate the CI/CD process. GitHub Actions is built into GitHub, facilitating CI/CD operations. Users need only invoke a menu and upload their YAML

configuration in order to initiate continuous GitHub operations.

5. Setting Up Azure DevOps

In this section, we will execute the first phase of the sample web application's CI/CD setup by using Azure DevOps. In our experience, Azure DevOps offers the most intuitive and feature-rich service for setting up CI/CD pipelines. First, we will create a sample web application project running the code for a “todo” list. Next, we will showcase the process of creating a new project in Azure DevOps to prepare our environment for further configuration. Once our project is created, we will create a sample on-premises Git repository for our web application's code. We will then demonstrate how to configure a pipeline to build our code and validate if it works as expected. These foundational steps are required before we can actually implement the CI/CD pipelines. Obviously, you can also execute the steps in any other web application hosting location for which Azure DevOps Services supports. We chose Azure DevOps Services here for its feature-rich interface and intuitive integration, as well as its myriad integration options.

5. Creating a New Project

For our sample web application, we will host the on-premises Git repository in Azure DevOps Server for the code required to build our “todo” list web application using the ASP.NET core framework. We host the actual web application for demo purposes in an Azure App Service behind the Azure Front Door Service, which is a part of the Azure Infrastructure Services. These initial steps not only showcase the capabilities of Azure DevOps Server, the commented code actions are intentionally showcased in the demo files to enable further exploration by the readers interested in implementing the actions. Ideally, you can try executing these initial steps showcased on a test Azure DevOps project before using them in your production project since it will help familiarize you with its interface and configuration steps.

5.1. Creating a New Project

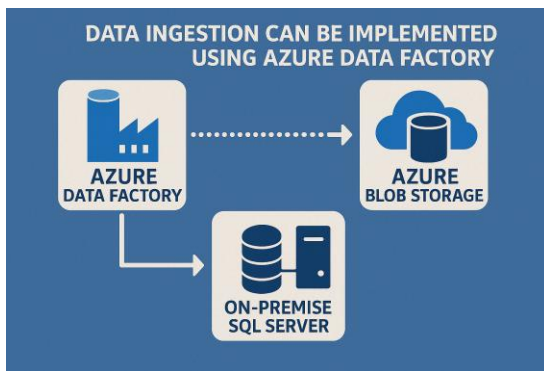
In order to begin working on projects in Azure DevOps, a new project must first be created. This includes a separate Git repository for the project's files and folders, which can be set to either public or private. Azure DevOps also natively

allows for managing work items, and optionally for adding CI/CD pipelines and artifacts as well. Work items can be organized in backlogs, structured in boards, and logged through sprints, just to name some of the functionalities provided.

However, Azure DevOps provides an overlap of functionalities. It also provides CI/CD capabilities through build and release pipelines, and artifact repositories. On the other hand, GitHub provides all these functionalities for free, and has been catching more Azure DevOps customers lately. As we will soon see, we will actually be configuring GitHub Actions workflows for CI/CD pipelines while accessing and copying compiled artifacts from Azure DevOps. You can give it a try for any project as well. This section will describe the steps needed to create a project in Azure DevOps while setting it up for collaborating with GitHub Actions for CI/CD.

In order to create a new project in Azure DevOps, log in and click on the New Project button. This will take you to a page where you will have to provide a name, description, visibility (Public or

Private), and some other options: version control (choose Git), and work item process (choose Basic). After you create your project, click on Repos in the left hand menu, and accept to set up your first repository. You can either create a new repository or import one; for this example please create a new one, as this is a beginner tutorial.



5.2. Configuring Repositories

After creating a new project in Azure DevOps, the next step will be provisioning a repository. Here you have several options to choose from: create a new Git repository, import a new codebase, or link to an existing repository.

In order to create a new Git repository, you need to provide a name for it. Azure DevOps will automatically create a new Git repo with an empty readme file. If you want to automatically clone this repository locally, be sure to uncheck the

option when creating it. If you select this option, cloning will fail due to the resulting empty repository.

By selecting the "Import" option, you will be able to import a new codebase into an empty repository. Besides, you must specify the type of repo you want to import: another Git repo, an SVN repo, or a TFVC repo running on an Azure DevOps server. In these cases, the repository will be created automatically. After importing the codebase, it's possible to create a new repository manually or link to a repository.

A common scenario is the import of a codebase from another Git repository. This could be required for different reasons: possibly, the other repository was located on another Git service and its migrated to Azure DevOps, maybe a Git repo running on an Azure DevOps server was created a long time ago, and you need to use it again, or simply, you need to use a repository. In these cases, it's advisable to import the codebase to Azure DevOps instead of cloning it and pushing the local copy to the new repository.

5.3. Setting Up Build Pipelines

In this chapter, we are going to create new build pipelines for all the microservices

contained in the Azure DevOps repository we created in the previous chapter, in the Azure DevOps organization. These build pipelines will create the docker images for the connected microservices, push them to the Azure Container Registry, and publish the web application components. This task will be executed in the first pipeline creation and then, a release pipeline will reuse the component images and repeat the task for all the environments upon request. These tasks can be created manually, uploading functions and creating the necessary commands line by line. But it could be really tedious work because a lot of commands must be created. Alternatively, Azure DevOps has a service that helps the developers solve this problem. The service is like your script generator. It detects all the microservices projects in the solution, runs locally the first necessary build and publishes the Azure DevOps commands that will generate the pipelines containing the commands without the pitcher work. Then, the only task left is to configure the parameters for each pipeline, parameters that are different from the default

parameter values we use to create the pipelines.

To run this chapter, the developer must be logged into the Azure DevOps organization account created in the previous chapter. The Azure DevOps Pipelines service must be activated by the organization owner. We must use the Azure DevOps local DevOps Credentials Manager to authenticate our local computer to the Azure DevOps organization created in the previous chapter. Both the DevOps agent and the DevOps CLI tool must be installed in the local computer. The solution with all the microservices must be developed and ready to be pushed to the Azure DevOps repo. This task should have been completed in the previous chapter. The Azure Container Registry must have been created using the Azure CLI. The Azure Container Registry name must be contained into the environment variables.

6. Setting Up GitHub Actions

GitHub Actions are available on all public and private repositories, and they are free on public repositories and on private repositories within the GitHub Free, Team, and Enterprise Cloud organizations. GitHub Actions enable not

only the automation of software build and deployment processes, but also configuration of workflows that react to GitHub events like comments on issues, new issues, pull request merging, or Git pushes. Repositories used for deployment may be on the same or another GitHub account. Workflows are defined in a workflow YAML file that is stored within the configuration repository, and they are organized in jobs, that are executed in individual virtual environments. GitHub Actions executes jobs sequentially unless you explicitly declare them in parallel. Jobs either run on GitHub-hosted virtual environments or on self-hosted runners where the packages, libraries, and development tools needed for your project build or test are installed.

Creating Workflows

Workflows are defined in a YAML file that is stored in the “.github/workflows” directory of your repository. In addition, you can also create a custom “.github/” directory for workflows and GitHub Actions commands related to your project. In this custom directory, you can create three directories named “actions”, “bin”, and “workflows”, which hold action definitions, command binaries,

and workflow files, respectively. Each workflow has one or multiple triggers, which configure the workflows to be executed on the occurrence of relevant events on the repository. Each workflow can define one or more jobs, which is a set of steps that can run sequentially or in parallel. Each step can be an action being invoked in the job execution, or a shell command being executed in the job environment. All the steps in a job execute within the same virtual environment while the jobs set to run in parallel execute in their own virtual environments, which may be different. The workflows are defined in the repository along with your project source code ensuring that these workflows can be version controlled with the related code.

6.1. Creating Workflows

Creating a GitHub Action requires the creation of a workflow file, which defines how to run a given project. This file is created in the “.github/workflows” relative folder to the project or repository. The workflow file can exist in any branch or pull request of the repository. GitHub will only be able to run the action if the workflow file exists in the master branch for public projects and in the default

branch for private repositories. GitHub Actions support only YAML file format, using the extension ".yaml".

Workflows are triggered by different events or a combination of events of the GitHub services. The events may be a push to a branch or pull request, a software release, the submission or modification of an issue, milestone or discussion, etc. Workflows can also be triggered by a schedule and workflow dispatch. Recent events can, of course, have an input; however, for security concerns, you should not create event payloads with sensitive information such as secrets and tokens. The entry action workflow consists of jobs, which in turn consist of steps to execute. Jobs can be run in parallel or sequentially, but for that the value of the workflow attribute should be set to the "workflow" keyword. Each job runs in a virtual machine. As noted earlier, a workflow is defined in a workflow file residing in the ".github/workflows" directory of the repository.

A workflow can include a set of standard environment variables that are automatically accessible for use in the workflow. These variables allow actions

in the workflow to access the contents of the event that triggered the workflow, GitHub context, secrets, etc. In addition, different types of job contexts are made available. Contexts or specific information related to the workflow can also be passed on to action steps, which are and execute commands in the virtual environment.

6.2. Using Actions from the Marketplace

One of the advantages of using GitHub Actions is the availability of many pre-packaged actions available at the Actions Marketplace. They can help reduce time to create new workflows with functionality already implemented by the Action you chose and tested by the community around it. It is highly recommended to explore the Action you selected and understand which features it exposes, including accepted parameters, permitted events and outputs, as well as its licensing model. From the Marketplace, you can easily navigate between the learning materials published there and get the Action integrated with your repository. To get started simply use the "New Workflow" button at the right, Action Marketplace page, also available in your repository. You will also note a

section called “Workflows you may want to use” that brings a curated list of already built workflows, based on your repository configuration.

To configure a new workflow using an Action from the Marketplace, simply navigate to the Action page and click the “Use this Action” button in the top area of the page. Once there, acknowledge the supported events, inputs and outputs in the provided tabs. You need to select the release tag version you want to use, check the documentation at the right specifying the parameters you want to set, and copy the code snippet to replace an entry in the new workflow template, pointing to it. After that, you can add your code snippets according to the Action you are using and eventually submit it when you are finished.

Actions that need to be configured to provide specific functionality in GitHub workflows are called Configurable Actions. For that, you will need to create an Input Parameter to specify what you want the action to do, an Output to indicate the action result back to the workflow, and a README.md file clarifying how this action should be configured by workflow authors.

6.3. Custom Actions Development

This chapter was created with the support of an action that checks the compatibility of organization packages with the v1 of the changes that are going to be published. This action was written in JavaScript by utilizing the provided API as a dependency. As it is not generic, the action is not published in the Marketplace yet. To be able to execute the action, it needs to be stored either in the repository or preferably in a public repository. In any case, it needs to be referred by commit SHA or branch name.

You can learn the basics of how to write actions in the documentation and explore other examples. There are also references to tutorials and community built actions. In the action examples, they will include some testing capability. The testing is usually performed via a JS library or via a third party package that can mock API responses. To be able to execute this action, you should have access to the API either via a personal access token stored in a secret or the platform itself. The security credentials should be able to access the repository that you want to check for the results. By utilizing action inputs and outputs, your action might become generic or be usable to multiple

people. But you can also build an action that really suits your internal needs like the one in this chapter.

In some of the previous chapters, you had examples of how to test those community-built actions, but you can do automatic testing better, by using the leads to mock API repo responses and simplify your test execution. This is very useful if you plan to create a generic action available in the Marketplace. But if you are to write internals that cater to your need, you might feel the need to do manual execution like we do here. For internal-use action that executes sequence of commands to fetch custom data at the development stage, the manual testing should be sufficient because of the iterative design.

7. Integrating Azure DevOps with GitHub

Azure DevOps and GitHub are distinct entities that can be integrated, enabling a collaborative environment and extending the capabilities of GitHub tools and workflows. This section describes how to integrate Azure DevOps with GitHub by linking repositories hosting code or containers and setting up Azure pipelines to be triggered from GitHub events.

Using these capabilities, Azure DevOps can augment GitHub Actions offering and help implement more complex workflows not supported by GitHub Actions.

7.1. Linking Repositories

Using link integrations, organizations or individual users can link GitHub repositories to Azure DevOps organizations or projects to help build a meaningful development experience for developers who use tools from both GitHub and Azure DevOps. Officially supported integrations are available for GitHub.com accounts and organizations and GitHub Enterprise Server version 2.22 and later. These capabilities enable developers to gain deeper insights into GitHub code repositories and GitHub Actions user workflows by surfacing activity in Azure DevOps boards. Users can leverage boards features while never leaving GitHub, choose to import or sync GitHub Issues and related comments for work tracking in Azure Boards, view boards activity in the timeline of the corresponding GitHub Pull Request, connect Azure Pipelines with GitHub Actions workflows, share reusable pipelines across your organization, and

sync pipeline comments with workflow comments automatically.

7.2. Triggering Azure Pipelines from GitHub

Azure Pipelines can be triggered from GitHub events. The following events trigger Azure DevOps Pipelines: creating a pull request or completing a pull request; pushing a commit or directly publishing a branch; submitting a workflow_run event; publishing a release; commenting on a workflow_run event; syncing a commit; creating a deployment, deployment protection rule, or environment; triggering a workflow_dispatch event; and triggering a repository_dispatch event.

7.1. Linking Repositories

GitHub has become a more important Unity project asset and source code library than ever. The first Online Services Unity3D SDK was built to mirror the C++ code in the PlayFab repository. As stated earlier in this text, some of the largest game studios have now moved their entire powerhouse game client logic on Unity over to using PlayFab. For these studios, all source code, tests, CI/CD, etc. are all centralized in GitHub.

Likewise, many of the backend services provided by PlayFab also use Unity as a dependency, and as stated in previous chapters, many companies and game studios build off of PlayFab to create their own customized game services. These companies need to integrate PlayFab services into their own backend solutions, many of which are Open-Sourced as SDKs. For these reasons, both our PlayFab SDKs, as well as the PlayFab Online Services SDK now have their CI/CD using GitHub Actions.

This chapter will show how to trigger Azure DevOps Pipelines using Webhooks, but first let's set up our integration. GitHub Actions also provides a native way to integrate seamlessly with Azure Services, so it is simply a matter of configuring either one SDK's pipeline service to fire the other when code is pushed, changed, or marked for specific testing. Before creating a Workflow YAML file, we need to authorize the integration from GitHub. Likewise, in order for Actions to call Azure DevOps REST APIs to trigger builds, we need to create a service connection to properly authenticate those requests.

7.2. Triggering Azure Pipelines from GitHub

Azure DevOps is a Microsoft service for managing and executing each step of the software creation process. One of the key components of Azure DevOps is Azure Pipelines, a tool for configuring continuous integration and deployment workflows. GitHub provides similar capabilities with GitHub Actions and GitHub Workflows, providing a native asset on Git-based repositories and supporting many file and container formats. With these two products, GitHub allows clients to create GitHub workflows and Azure DevOps allows clients to create Azure Pipelines.

It is common to want to execute a Pipeline for an Azure DevOps Project when a defined event is raised in GitHub. Azure DevOps supports pulling all relevant GitHub events, or only selected events, using two methods: a GitHub App and a Personal Access Token. A similar integration supports Azure DevOps to send selected events to trigger a GitHub Actions workflow. The Azure Logic Apps connector for GitHub allows functions to execute a GitHub Action for a repository when selected events happen in an Azure DevOps Project. Azure

DevOps provides a REST API for running an Action within a GitHub repository. The integration is not for general use, being limited to Azure Marketplace.

8. Best Practices for CI/CD Pipelines

CI/CD pipelines are designed with best practices to 1) enable collaboration across teams, create faster releases with fewer defects, and 2) increase the business agility with its high level of automation. The practices also provide configuration as code allowing for reproducibility for the pipeline itself for validation as needed. These practices include:

Version Control Strategies: Source control plays a major role in collaboration across teams. The source control repository for the code and other dependencies provides a history of changes made and can also be rolled back to a previous version if needed. The organization can define a branching strategy for the Git repository to reach less defect with code merged to production. Addition of features can be done away from the main branch using feature branches and can include automated testing via CI/CD on each commit on the feature branch. Changes

can be merged back to the main branch after enough validation via Pull Requests. It is a good practice to make each commit small changing a coherent part of the codebase to ease tracking over time. PR reviews are useful to ensure quality and share knowledge across team members.

Automated Testing: Validation is key for high quality software deliveries. Manual testing over time becomes unsustainable, so automated testing becomes necessary. The unit tests should be run as a part of each commit into the repository. Once basic validation of code structure and functionality are successful, integration tests can be scheduled on a pipeline to validate the interaction between microservices, modules, or components. Functional, performance and security tests should also ideally be automated and scheduled in a dedicated pipeline. Security scans on dependencies should be enabled and scheduled to avoid use of any vulnerable libraries. Code coverage can also be added to add additional validation before pull requests are approved.

8.1. Version Control Strategies

Version control forms the backbone of any DevOps process, therefore it is only logical that one should carefully consider

how to segment the application code responsible for each deployment. Each microservice should live in its own repository, separate from the rest of the dependencies, which could be the rest of the microservices or shared libraries. Other resources needed for deployment, like infrastructure as code templates, should either live in the microservice repository or in a separate repository. Careful thought also needs to go into which files and folders should live inside the repository. Configuration that varies from one deployment to another, multi-environment configuration, secret values, generated files, and binaries, or “build artifacts,” have their own best practices for storage and protection.

It is advisable to keep environment configurations separate but versioned alongside the code. This maximizes security while allowing you to roll back to previous versions if necessary. Secrets should be protected either by a secret storage approach or using a key vault along with the secrets as mentioned in earlier sections. Build artifacts do not belong in the source repository. They are tools of the development process meaning they occur during the developer compile/test/validate cycle and should

not persist in source control after that cycle. To help manage files, in addition to creating the right file when creating your repository, you should also assign certain extensions to different collaborators to help with organization and reduce the risk of accidentally uploading sensitive files.

8.2. Automated Testing

Tests not only check the correctness of a system but also provide documentation on how its components are intended to work. Automated tests are the most powerful type of tests and are primarily used in the Continuous Integration phase. It is important to keep in mind that test automation will not be effective if test planning is bad. When designing tests, keep the following factors in mind. First, automate all repetitive tasks. Tests will save testers time and effort, allowing them to complete the testing task more quickly, without dropping quality. New features should be thoroughly tested before being included in the release. Test that the inputs produce the expected outputs to validate functionality. If the code breaks, notifies developers that neglecting the tests. Improving code quality costs much more than testing the code.

More assertive use of Automated Testing phases takes place when we use an Automated Testing Framework. The framework should consider unit test, integration test, system test and acceptance test. Unit Tests have the function of testing the logic of each function/module/class of the application in isolation from the rest of the system. The implementation of unit tests should be the developer regardless of the programming language used. Developers need to make unit tests covering, at least the conditions of Success or Error that each method or function can have. There are several tools that make coding unit tests easier. However the implementation of unit tests is not everything, would be a first layer to cover responsibly and minimize problems of any installed version. BDD is a way of bringing unit tests to another level. Transforming these unit tests, that will verify the application logic and normal flow into readable and understandable by business analysts and stakeholders desiring to compile acceptance test, guiding the implementation of a functionality.

8.3. Monitoring and Logging

As organizations adopt CI/CD practices, it becomes crucial to understand how

these deployments are functioning over time, and gather insights about possible issues. While there are dashboards with logs per each deployment, this will not be enough to understand larger trends in deployment quality or frequency. For both Azure Services and GitHub-hosted Applications, insights can be gathered in Azure Monitor, which can be integrated with many Azure Services, such as Web Applications, API Management, Functions, Service Bus, BLOB Storage, Azure Kubernetes Service, and more. Additionally, Application Insights, part of Azure Monitor, can be integrated with Azure Services to gather monitoring and logging data in the same location.

While there are some CI/CD tools that may provide dashboards regarding the quality of the pipelines, these are usually limited to the surface level. Using Azure Monitor and Application Insights to gather monitoring and logging data of the deployed applications, it is possible to gain a deeper knowledge of how the application behaves once deployed, and relate this to specific changes pushed to production.

For example, the number of failed requests for a web application can be

easily checked on both the Azure Portal - where it can be correlated with the latest CD runs for that application/back-end - and the Application Insights dashboard. A sudden increase in failed requests may be the result of a deployment broken into production that didn't trigger the alarms nor was caught by other means. Such a scenario may lead developers to investigate the results of the last deployment, find the failing change, and make the decision on whether to revert it or fix it, or wait for the next development cycle to correct the issue, which is common with data-related problems.

9. Security Considerations

This chapter is aimed at readers who are looking for information regarding security for their CI/CD pipelines. Securing CI/CD pipelines is essential to protecting the code and technology stack. There are usually multiple contributors to a project, and we need to ensure that access is only for users permitted to make changes to the code at any time. We also need to protect any secrets used in running actions or tasks in pipelines. Doing this will help to mitigate the risk of abused pipelines.

This chapter provides useful information on how to secure both Azure DevOps and GitHub Actions, with an emphasis on how to store secrets in the systems securely and permission management. These are very important for onboarding any new organization as any rogue actor who can push code into a repository can abuse the CI/CD for malicious purposes.

9.1. Managing Secrets

Secrets in both Azure DevOps and GitHub Actions can be managed via a similar interface mechanism. Organizations might have to connect to third-party API endpoints that are only accessible via a secure token; these tokens are usually predictable and need to be stored securely to avoid detection and misuse by attackers. Attackers may use the CI/CD pipeline to push malicious code or run cleanup code into the production systems. Secrets can be created via the UI, CLI commands, or manually via a JSON/YAML file. APIs provide mechanisms to store the secrets securely—they store it in a secure vault. Secrets must be rotated more frequently, made specific to a single action or task, and contributors should be granted limited permissions.

9.2. Access Control in Pipelines

Access control allows determining what contributors can do on the platform. Access control is typically role-based in both Azure DevOps and GitHub Actions, where permissions can be set for contributors without altering their capabilities. In GitHub Actions, roles are assigned to the users who create the workflows. Access control to events, such as pull requests or pushes, can be controlled. Permissions are checked when a workflow is triggered that was initiated by a specific action.

9.1. Managing Secrets

Secrets management is key in CI/CD pipelines, as secrets can be leaked even without any user interaction, for example when building an application that submits and publishes test results in a channel or creates a release. Many teams give explicit permissions to the pipeline only for the repositories containing the code that matches with the given secrets. This is usually possible in organizations that work around multiple clouds, and the same type of resources exist in each cloud. However, some teams manage their secrets and sensitive information out of their repositories but under a group

permissions for all pipelines that make use of those secrets and sensitive information. This is a good approach as it avoids hardcoded secrets in the code. In this chapter, we present how a platform and another platform manage secrets in pipelines in a practical way.

One platform allows defining secrets in variable groups of the organization with encrypted variables during execution. The group can be a variable group associated to a pipeline or can be managed by a service connection in case the pipeline is going to be consuming service from the resources using the secret. Secrets cannot be logged, except manually, and their value will be masked in logs. Also depending on the permissions set, secrets can be leaked when using tasks, and services in the pipeline that do not have the same permissions as the secrets defined. Moreover, managed service identities cannot be used inside hosted agents yet, meaning that you need to create your credentials manually and to encrypt them in the pipeline to use them. Secrets can also be set syntactically in the pipeline file, making the secrets not to be masked nor encrypted in the pipeline execution.

9.2. Access Control in Pipelines

Data security is vital in any software delivery process, and Azure DevOps and GitHub Actions provide a number of mechanisms to control access to your pipelines and maintain secrets. The goal of this section is to outline relevant access control mechanisms provided in both systems. One of the primary concerns regarding using a CI/CD pipeline is the exposed application source code and other sensitive data. While pipelines process the application source code and might utilize other secret variables, they can be configured to be public for any member of the community with access. If you do have a public facing configuration for any pipeline, it will require proper sensitivity measures to keep any secrets that interact with it maintained securely. GitHub Actions and Azure DevOps provide ways to secure sensitive data, monitor the pipeline activities, and enforce restrictions based on threats or damage assessment. GitHub Actions and Azure DevOps provide various mechanisms to secure your code repository from unauthorized access. You can choose to keep your repository public if you want the world to access the contents, or you can choose to keep your

repository private from being accessed by the general population. Access control lists (ACLs) allow you to create a team and grant specific permissions to that team (or individual). Azure DevOps also allows you to manage access on organization, project, and repository levels. You can specify different access control levels for each of the areas while also restricting external users. You also can enable Auditing of your Azure DevOps account, to identify suspicious account activities.

10. Common Challenges and Solutions

While implementing CI/CD pipelines offers significant benefits, organizations may encounter challenges along the way. This chapter addresses common issues that users may experience and provides practical advice for overcoming these challenges. Two of the most common issues when setting up CI/CD pipelines are handling build failures and optimizing performance.

10.1. Handling Build Failures

Build failures are a common occurrence when first setting up a pipeline, making it especially important to closely monitor CI/CD pipelines for errors as they run. When troubleshooting a failed build or

pipeline, there are a number of key things to look for in associated log files. First, check that the right repositories, branches, and build triggers are being used. Then, look for issues relating to builds in a shell execution environment, as well as problems installing software and dependencies and copying files. Checking for Git credential issues can be valuable, and certain operations only fail on pushes and PRs, so compare the operations to learn what works and about how to mitigate for anything that's off.

Another potential source for CI/CD failures is that you may not be running the right build pipelines for the target devices. For example, if you're building Windows executables or binaries targeted for ARM-based devices, and a target device isn't part of the build triggers, it can impose building for all target platforms. Make sure to use appropriate target and build conditions for both regular and triggered pipelines to only build for the right platforms.

10.2. Optimizing Pipeline Performance

Sometimes a pipeline may complete successfully but take longer than users expect. Speeding up the CI/CD cycle is one of the most important things that can

be done to increase developer productivity. There are many ways to optimize the performance of your CI/CD pipelines. For workflows, if specifying more jobs to run and using more parallelism for a workflow, remember that the overall run time is only as short as the longest-running job, so jobs that run sequentially can slow things down significantly. Also, carefully analyze workflows that have many jobs dependent on each other, as one long runtime job can add a significant amount of time to the overall pipeline execution.

10.1. Handling Build Failures

Build failures are a common occurrence during development work. As application code changes, it can often cause the code to fail to compile properly or break any automated tests that are performed. When the build fails, the developer can get hold of the latest pipeline logs to inspect the errors and get a guided approach to fix it. Once resolved, the developer will make some changes to the code to resolve for the errors which will trigger the CI workflow. But what if the build failed not due to any fault of the developer, or it happens for every developer who implements a new change to the code and

debugs it. This is very common with the work with change request management.

To manage for this, there are two types of retries that can be set up for build jobs. The first is a manual retry that the developer triggers when they notice the CI has failed. This can be viewed as a failure for which the CI did its job of informing the developer of a fault but could be managed better through better logging. The second is an automated retry that is performed automatically by setting the max-attempts attribute in the job-level defaults section of the composite action. By taking advantage of workflows that are run as a path filter, multiple different workflows can be used concurrently to minimize the change between runs and let the developer concentrate on focused debugging of the feature change implementation.

10.2. Optimizing Pipeline Performance

Software development teams rely on CI/CD pipelines to expedite product releases, yet long pipeline execution times can become a source of frustration for developers. With every interaction with the pipeline – such as developing, debugging, testing, and reviewing changes – time away from productive

development becomes significant, particularly with larger repositories or extensive test suites. Developers face delays while waiting for reviews on code that has been merged. These delays largely stem from slow CI processes, but efficiencies gained by optimizing CI/CD pipelines would not only reallocate developer time, but would also lead to reductions in infrastructure resource consumption. CI/CD processes for large, complex projects typically requiring significant investment to optimize hope to offer a combination of automation and education to assist development teams with this process.

These optimizations fall into at least three categories. The first category includes optimizations that help prevent pipelines from running needlessly. These optimizations make lower-level decisions about whether or not to run a pipeline based on features of the incoming pull request. The second category encompasses optimizations to help make pipelines run more efficiently when they do run. These optimizations explore opportunities for parallelism and caching to improve pipeline performance. The last category is a bit less common; while inquiry into pipeline performance (in the

form of logs and metrics) can be expanded to provide better automatic recommendations to help speed up CI/CD pipelines.

11. Case Studies

In this chapter, we will discuss some case studies based on our research and experience working with different organizations worldwide. The primary goal of these case studies is to share more practical examples with our readers after learning from their mistakes and successful implementations. This will enrich the knowledge gained throughout this book. We think that no continuous integration and delivery (CI/CD) implementations are the same, as each organization comes from a different area, works on different technologies, software, and teams, and has different customer and task types, business requirements, and revenue models. Each organization will have its own good and bad experiences while implementing CI/CD. However, through these case studies, we hope you will gather enough knowledge on how to implement CI/CD pipelines from the lessons learned in the failures of other organizations while also gathering more information about how to successfully automate your pipelines,

thus accelerating your team's maturity regarding time requirements.

The main goal of CI/CD is to reduce the delivery time of smaller functionalities to our end-users by automating the entire delivery pipeline. While doing so, there are problems and challenges faced on a daily basis. Not all organizations implement CI/CD pipelines based on solid foundations. Each organization has its own reason for implementing defined CI/CD processes, with different stages of maturity. Not all of them learn correctly to execute daily operation tasks, but instead, use them to tick boxes. In this chapter, we will go one step further to share some of our experiences with some CI/CD user organizations.

11.1. Successful Implementations

Whenever any new techniques or technology is made for implementation, the primary concern of organizations is whether the initiative will be successful. A good technique is one that is simple to use, economical, align with the given parameters, and sufficiently flexible and adaptable to different needs and situations of an organization. More so when the business is led by increasing competition. In this regard, a good

number of models for implementing Continuous Integration and Delivery have been documented to demonstrate their success in streamlining and automating the procedures adopted, thereby enhancing the speed of delivery of products to the customers.

In this chapter, we document a case of a small yet rapid growth start-up organization with less than 30 employees in the e-learning domain. The extensive usage of technology to create a one-stop platform for students and tutors, augmented by seamless integrations with payment gateways, chat support, blog and video hosting services, and others, has enabled the business to gain market share. However, the technology stack being PHP poses challenges especially when it comes to improving the software quality. Better code quality involves performing static code reviews, performing vulnerability and performance screening, and doing unit testing before the application deployment on production. Failure to do so can result in degraded performance during peak times when a large number of users are using the platform simultaneously. For a business operating in the 21st Century, a slow, unresponsive site during peak periods is

nothing short of a disaster. Most of the challenges are related to lack of implementing a Continuous Integration and Delivery or Deployment process. The primary goal of the CI/CD process is to automate the software and delivery lifecycle, increase the frequency of code releases, and improve software quality and security.

11.2. Lessons Learned from Failures

The following lessons were learned through those failures and provide some lessons learned for organizations that want to bridge between CI/CD pipelines. First, avoid thinking of a CI/CD pipeline as solely a series of steps executing in a temporary environment. While most implementations of CI/CD do encourage lean, micro-solutions to principle, provide as clear of a path for both actions systems to communicate back and forth as makes sense for what will be kept in which system. This provides the best for any projects that do share and helps the overall process by presenting a clear integration design to new developers on a project who may only know one of the two. Second, disallow or at least certainly monitor the creation of actions outside of the main actions repository, especially if one system will always be the source of

truth for build and deployment processes. After the CI/CD bridges have been built, valid builds that have passed code quality checks or otherwise needed testing will come for features developed in either system. If badly defined actions are allowed to be created, these actions can result in shorter long-term lead time and bad build status stickers if those builds are not properly gated.

Third, if build and deployment steps are going to be split between systems, be careful about what code quality checks are done in which system, or alternately make sure that steps in checked workflows are always gated such that the checks have run successfully in one system before the respective steps run. If code quality checks such as code analysis, unit tests, acceptance testing with test containers, and security testing are allowed to run without any such gates in place, the builds can take reached 50 minutes to run before.

12. Future Trends in CI/CD

Since productivity is at the root for organizations that have thrived to this day, small incremental improvements are imperative. Companies look for a competitive edge over their competitors,

and CI/CD pipelines enable that. As such the race to innovate and be the first cannot be undercut. CI/CD opens the opportunity for combining smaller teams, or “squads”, that work on all stages of the product; from ideation and UX, to experiments, from implementation and development, to building and deployment, monitoring and operational management. It promotes reducing silos and minimizing friction both inside the teams and outside with other squads and management.

With “Everything as Code” being popularized, and still early on its adoption journey; organizations benefit from storing everything in source control: from infrastructure, to pipeline automation configuration files; from manifests and deployment configurations, to secrets. What new tools are enabling this? Templates on both actions and YAML pipelines are making it easier to auto-generate configuration files, be it for Infrastructure as Code pro, for patches libraries, basic delimiters for Terraform or for Grafana; and by pre-inflating reusable workflows designed in collaboration to easily plug security checks and even deployment hooks onto an existing pipeline. On the pipeline

architecture layer; adopt a GitOps approach to pipeline design, in which an observability system listens to source control activities for CI/CD specific files, then reacts by auto-generating a pipeline on commit. If authored either in YAML templates, or in Terraform; the observability service would then deploy it immediately while for other tools the service would register the new pipeline with it.

13. Conclusion

If there is any topic discussed in this book, it is related to the desire of achieving an ever-easier way of managing DevOps processes, using techniques for automating what can be automated. In this sense, Continuous Integration and Continuous Delivery Pipelines encapsulate this aspect in a more practical way. During the chapters of this book, we presented an easy, straightforward way for creating, managing and configuring CI/CD Pipelines. Moreover, we also presented real-life examples, demonstrating the advantages of adopting these tools for creating, managing, configuring and enhancing CI/CD pipelines.

Any DevOps endeavor is tempted by the need of making things easier, integrating, coordinating, automating what is possible. With that, we hope the tools and solutions presented along this book provide to our readers a comprehensive overview of using these tools for effectively creating Continuous Integration and Delivery Pipelines. With this book, we provided guidelines, rules of thumb, tips and pitfalls to help the DevOps engineer explore these tools, make the software development processes easier and faster, making the deployment of solutions to production a walk in the park (okay, not that easy), but at least less error-prone. We hope you enjoyed reading it as much as we enjoyed writing it!



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