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The Digital Harvest: Opportunities, Challenges, and Business Potential of Digital India in Indian Agriculture

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Abstract

The **Digital India** initiative, launched by the Honourable Prime Minister Shri Narendra Modi on July 1, 2015, is a monumental effort aimed at transforming India into a globally competitive, digitally empowered society and a vibrant knowledge economy. Its foundational vision rests on three pillars: **Digital Infrastructure as a Utility to Every Citizen, Governance & Services on Demand, and Digital Empowerment of Citizens**. Given the agrarian nature of the Indian economy, where over 60% of the population relies on agriculture, the success of Digital India is inextricably linked to the digitalization of farming. Agriculture contributes approximately 17% to the nation's total GDP, making its sustainable and efficient growth paramount for achieving the **"Viksit Bharat"** goal by 2047.

This comprehensive research paper investigates the profound implications of the Digital India Programme on the agricultural sector with an expanded focus on the **emergence of digital agriculture as a business ecosystem**.. It details flagship initiatives such as the **Digital Agriculture Mission (DAM), AgriStack, Krishi Decision Support System (Krishi-DSS), and Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)**, while also incorporating a **market-oriented analysis of the digital agriculture sector**, including an overview of market size and the supply of digital agricultural technologies and services. Through a focused empirical study of farmers in the Rayalaseema region, the paper analyzes the opportunities, limitations, and challenges farmers face in adopting these technologies. The findings underscore the critical influence of demographic factors, such as gender and age, on technology knowledge, interest, and perceived reliability. The paper concludes that while high initial costs, limited rural connectivity, and digital literacy gaps present substantial barriers, strategic policy reorientation, particularly through the promotion of Farmer Producer Organisations (FPOs) and the democratization of affordable, vernacular-based digital tools, offers a clear pathway to unlocking the transformative potential of digital agriculture and ensuring inclusive growth across the nation's farms.

Keywords: Digital India Programme, Digital Agriculture, Precision Agriculture, Smart Farming, AgriStack, Krishi-DSS, Market Size, Digital Agricultural Technologies, Farmer Producer Organisations (FPOs), Subscription-based Models, Pay-per-use Platforms, B2B Solutions, AI in Agriculture, IoT in Agriculture, Technology Adoption, Socio-Economic Impact, Rural Connectivity, Digital Literacy, eNAM, PM-KISAN

1. Introduction: Digital India and the Agrarian Economy

1.1 The Digital India Vision

Digital India is a flagship programme launched on July 1, 2015, with the core objective of connecting rural areas with high-speed Internet networks and enhancing the digital literacy of citizens. The

programme's vision is centered on inclusive growth across electronic services, digital products, manufacturing, and job opportunities. Its relentless focus on developing broadband highways, ensuring universal access to mobile connectivity, and expanding digital governance has led to India achieving the third-place ranking globally in the digitalization of its economy, as confirmed by the Indian Council for Research on International Economic Relations (ICRIER) in its State of India's Digital Economy Report, 2024. This trajectory of growth is intended to be the backbone for realizing the aspirational goal of a **"Viksit Bharat"** by 2047, empowering citizens through social welfare, skill development, and education.

1.2 The Centrality of Agriculture

Even amidst significant advancements in various industrial and service sectors, India continues to be fundamentally an agrarian economy. The role of the farmer is undeniably high: over 70% of rural households depend on agriculture, and the sector employs over 60% of the population. Although its contribution to the total Gross Domestic Product (GDP) is approximately 17%, the health and sustainability of agriculture directly impact national food security, rural livelihoods, and macro-economic stability. Consequently, the application of technology for socio-economic development and the push for sustainable agriculture have become priority areas for the Government of India.

The government has undertaken massive infrastructure initiatives to support this goal. Under the **Bharat Broadband Network Limited (BBNL)**, there is a concerted effort to connect 250,000 villages. Furthermore, the plan includes creating 28,000 seats for Business Process Outsourcing (BPOs) in various states and establishing at least one **Common Service Centre (CSC)** in each Gram Panchayat (village council). A direct application to the agricultural economy is the ambitious target to digitally connect 550 farmer markets across the country, aiming to create a seamless, transparent, and barrier-free trading environment.

1.3 Research Objective and Scope

In view of the government's unprecedented initiative to digitalize the nation, the present study is undertaken to:

- **Investigate the opportunities and transformative potential** of the Digital India Programme for the agricultural sector.
- **Analyze the specific schemes and digital public infrastructure (DPI)** created to empower farmers.
- **Examine the limitations and challenges** faced by farmers in adopting digital technologies.
- **Empirically assess the adoption readiness** of farmers in a specific region, focusing on the **Rayalaseema region**, to understand the influence of demographic factors like gender and age on technology adoption, knowledge, and interest.

The ultimate goal is to provide evidence-based insights to inform strategic policy decisions aimed at fostering inclusive digital growth in rural India.

2. Theoretical Framework: Defining Digital Agriculture

The digitalization of agriculture involves integrating cutting-edge technologies into the farm production system to enhance efficiency, productivity, and sustainability. While the terms are often used interchangeably, it is crucial to establish clear definitions for a focused discussion.

2.1 Precision Agriculture vs. Smart Farming

The application of digital technologies in agriculture is categorized by various terms:

- **Precision Agriculture (PA):** As defined by the International Society for Precision Agriculture, PA is a management strategy that gathers, processes, and analyzes **temporal, spatial, and individual data**.

It combines this data with other information to support management decisions based on estimated variability, leading to improved resource use efficiency, productivity, quality, profitability, and sustainability. It is essentially about *doing the right thing, in the right place, at the right time*. Technologies include Geographic Information Systems (GIS), yield monitoring, and variable-rate application systems.

- **Smart Farming (Farming 4.0/Digital Farming):** This is a broader, umbrella concept involving the application of modern **Information and Communication Technologies (ICTs)** like the Internet of Things (IoT), robotics, drones, Artificial Intelligence (AI), and data analytics to optimize complex farming systems. The EU-funded BIOPRO Baden-Württemberg GmbH project dossier (2018) defines it as the integration of smart technologies and modern data technologies to enable informed decisions based on concrete data, thereby increasing resource and cost efficiency while reducing environmental impact.
- **Key Distinction:** Precision farming is often seen as a data-driven, controlled, and accurate IoT-based approach that makes decisions at the level of a square meter or even per plant/animal. Smart farming, conversely, encompasses the entire technological and data ecosystem that facilitates this precision, driving what has been termed the 'third green revolution' in agriculture.

2.2 The Role of AI and Data Analytics

AI and advanced data analytics are leading a new era of intelligent, data-driven agriculture.

- **Real-time Insights:** AI-powered advisory systems analyze multi-layered data from satellite images, IoT sensors, and weather feeds to deliver customized crop guidance and management strategies. This empowers farmers to proactively overcome challenges like unpredictable monsoons, market fluctuations, and pest attacks.
- **Forecasting and Optimization:** NITI Aayog predicted that AI in agriculture would be worth $2.6 Bn by 2025, growing at a 22.5% Compound Annual Growth Rate (CAGR). AI helps in creating seasonal forecasting models, optimizing crop selection, improving soil quality, and providing early warnings for disease outbreaks, which is crucial for achieving high annual growth rates.
- **Precision Applications:** Drone-assisted aerial surveillance, equipped with computer vision, enables real-time detection of crop health issues and allows for the precise, targeted application of pesticides or nutrients, minimizing waste and environmental harm.

3. Digital Public Infrastructure: The Foundation for Agricultural Transformation

The Digital Agriculture Mission (DAM), approved by the Government of India, is the cornerstone of a modern, data-driven, and farmer-centric agricultural ecosystem. It leverages Digital Public Infrastructure (DPI) to empower farmers with timely and reliable solutions.

3.1 The Pillars of the Digital Agriculture Mission

The key objectives of DAM are to create a robust digital ecosystem, improve transparency, support evidence-based policy, and promote innovation through public-private partnerships (Agri techs).

3.1.1 AgriStack: The Digital Public Good

AgriStack is envisioned as a digital public good, analogous to "Aadhar," built on a 'federated architecture' in collaboration with central and state agencies. It comprises three foundational registries:

1. **Farmers' Registry (Farmer ID):** A dynamic, accurate, and verified database providing comprehensive and authenticated details of farmers, including demographics, land holdings, family details, crops sown, and livestock. This Farmer ID, akin to an Aadhaar for the farm sector, is essential

for digital authentication to avail benefits like credit, insurance, and procurement in a secure and transparent manner. Pilot projects are underway in several states to create digital identities for millions of farmers.

2. **Geo-referenced Village Maps:** These serve as the base layer for all digital activities. Survey-level, geo-referenced cadastral maps are required for conducting digital crop surveys and enabling geography-based advisory systems, allowing for trustful ground truth data collection at the land parcel level.
3. **Crop Sown Registry through Digital Crop Survey (DCS):** This system collects accurate, real-time, plot-level crop area information directly from the field via a mobile interface. The DCS aims to replace traditional, manual survey methods (like Girdawari), and its data will be crucial for seamless crop area mapping using remote sensing, thereby reducing the need for future manual surveys.

3.1.2 Krishi Decision Support System (Krishi-DSS)

Launched on August 16, 2024, Krishi-DSS integrates and standardizes a vast array of geospatial and non-geospatial data, including satellite imagery, weather reports, soil profiles, crop signatures, reservoir levels, and government scheme information.

- **Evidence-Based Decisions:** Krishi-DSS offers essential tools like crop maps, soil maps, automated yield estimation models, and drought/flood monitoring systems. This supports the government in making informed, evidence-based policy decisions.
- **Agritech Innovation:** The platform facilitates innovative solutions by research institutions and the agritech industry, supporting crop map generation for diversification, and technology-based yield assessment for quicker settlement of crop insurance claims.

3.1.3 Comprehensive Soil Fertility and Profile Maps

The Nationwide Soil Resource Mapping project, initiated by the Soil and Land Use Survey of India (SLUSI), is inventorying soils at a detailed 1:10,000 scale. This detailed soil profile study, using high-resolution satellite and ground data, creates standardized soil maps for rational land-use and crop planning, promoting sustainable agriculture and fertilizer optimization.

3.2 Key Digital Services and Schemes

Beyond the foundational DPI, several services ensure direct benefit delivery and information dissemination:

- **Pradhan Mantri Kisan Samman Nidhi (PM-KISAN):** A technology-driven IT solution launched in February 2019. It provides direct financial assistance of ₹ 6,000/- per year to landholding farmer families in three equal instalments via **Direct Benefit Transfer (DBT)** into Aadhaar-seeded bank accounts. This is a critical example of digital governance delivering welfare efficiently.
- **SATHI (Seed Traceability, Authenticity, and Holistic Inventory):** This national portal monitors the entire seed production and distribution chain. Phase II aims to record the real-time movement of seed bags through **QR-coded seed bags**, providing end-to-end traceability and inventory management from the retailer to the national level.
- **Agro Based Advisory – m4Agri:** This mobile-based advisory system uses both a pull (farmer-initiated query) and push (expert-initiated advisory) model. It allows data transmission through voice, text, images, and videos, connecting farmers with experts who can access a centralized database of the farmer's history and farm details for personalized, timely advice.

- **Kisan Suvidha & eNAM:** Apps like Kisan Suvidha offer real-time weather forecasts, pest control advisories, and crop-specific tips. The **Electronic National Agriculture Market (eNAM)**, launched in 2016, integrates local wholesale markets to create a unified national market, enabling transparent, online bidding and price discovery for farmers, effectively breaking down market cartelization.

4. Market Size and Commercial Potential of Digital Agricultural Technologies

The potential size of the market for digital agricultural technologies depends on farmers' demand, which is influenced by the number of farmers who potentially benefit from the technology and have access to funds to purchase the technology. This demand is influenced by a range of factors, which are further explained in the following:

Level of mechanization and economies of scale: Since precision farming technologies are embodied in agricultural machinery, their market size is determined by the level of mechanization across different regions of the world. Digital technologies that exhibit economies of scale at the farm level lead to further limitations of market size, since only the larger-scale farmers are likely to adopt them. Economies of scale differ across the digital technologies listed in Table 1. They are likely to be the greatest for most precision farming technologies and least for the advisory apps.

Input prices, including labor costs and output prices: Since most digital tools aim to encourage more efficient use of agricultural inputs, such as fertilizer, agro-chemicals, and feeds for livestock; the profitability of the respective digital tools depends on input prices. As further pointed out below, this may create an opportunity for developing countries, where input prices are often relatively high due to transportation and transaction costs. Moreover, rising costs of farm labor, as observed in both developing and industrialized countries, will increase the profitability of adopting digital tools that save labor or facilitate the employment of less-skilled labor. Output prices, i.e., the prices of agricultural commodities, influence the profitability of the adoption of digital technologies as well.

Environmental regulations and public pressure: The public pressure for sustainable agriculture and organic food production in industrialized, as well as developing countries, is likely to increase the demand for digital technologies that reduce the use of agro-chemicals. The debate on glyphosate use is a prominent example. The pressure to reduce the use of fertilizers and pesticides provides an incentive to large agricultural chemical firms to develop farmer advisory services that promote the efficient use of these inputs and which could attract farmers to their products and increase the demand for agrochemicals.

Possibility to transfer the digital technology across regions and farming systems: The market size for digital agricultural technologies is largely influenced by the extent to which these technologies can be applied in different farming systems, possibly with adjustments, across the world. Large agro-input industries typically follow a strategy of making high R&D investments in genetic improvement of crops, development of active ingredients for pesticides, or construction of new agricultural machinery and then introducing these innovations to the largest possible markets worldwide. Since global agriculture relies on a rather limited number of crops and livestock species, this approach has worked rather well for these companies, even though regional adjustments are often required. To what extent a similar approach can be used for digital agricultural technologies depends on the type of digital technology. Advisory apps and farm management software, for example, need to be able to capture farm-specific and local conditions. This may be the reason software developers tend to concentrate on large countries with large areas of similar farming systems.

4.1 SUPPLY OF DIGITAL AGRICULTURAL TECHNOLOGIES AND SERVICES

There are four important types of firms investing in the development and marketing of digital agricultural technologies and services:

First, *large multinational agricultural input companies* supplying seeds, fertilizers, plant protection products (pesticides), and agricultural machinery. Typically, their headquarters are in the U.S., Europe, China, and India. They build up their digital agricultural services by investing internally and by buying small software and hardware companies. They can market digital agricultural technologies and services through their existing networks of dealers.

Second, *large multinational software and big-data companies* such as IBM, Microsoft, and SAP in the U.S. and Europe, TCS in India, and Tencent and Alibaba in China, are investing in digital agricultural technology.

Third, *nonagricultural "hardware" companies* developing digital agricultural technology. The German engineering firm, Bosch, is an example of a company that moved from providing hydraulic systems for tractors (among other products) to providing sensors and software for precision agriculture.

Fourth, *start-up companies*, which are the source of many of the most creative digital agricultural technologies in both industrialized and developing countries. Most seem to be independent entrepreneurs, often from outside agriculture (e.g., Hello Tractor). These start-ups are financed by venture capitalists or multinational input and tech firms. Some start-ups spin off from information technology firms, e.g., Climate Corps spun off from Google, while others spun off from input companies, such as Monsanto. Finally, some spun off from universities, for example, Agronomic Technology Corp (ATC) from Cornell University, which was purchased by Yara after being spun off.*5*

There is a fifth source—*agricultural processing and trading companies*—that provides information and inputs to increase farm productivity and the quality of products that farmers sell to them. These, however, are beyond the scope of this article.

5. Challenges and Opportunities in the Digital Ecosystem

The transformation of Indian agriculture hinges on overcoming significant structural challenges, while simultaneously capitalizing on new policy opportunities brought about by digitalization.

5.1 Key Challenges in Digital Farming

Despite the vast potential, the transition to digital farming faces substantial barriers, particularly for India's small and marginal farmers who constitute the majority of the agricultural workforce.

1. **High Initial Costs and Affordability:** The average income of an Indian farmer is estimated at Rupees 77,976 (approx. $1000) per year. This precarious financial state makes the upfront investment in costly digital tools (sensors, drones, advanced machinery) highly prohibitive. For technology to be adopted, it must be affordable and demonstrate a rapid return on investment (e.g., within one crop season).
2. **Limited Rural Connectivity and Infrastructure:** Inadequate internet access, especially high-speed broadband, in deep rural areas hampers the real-time data transfer essential for precision agriculture. The lack of reliable power supply and the high cost of data plans further compound this barrier.
3. **Digital Literacy and Complexity:** A significant portion of the farming population is illiterate or semi-literate, and many lack the skills needed to effectively use complex digital interfaces. Integrating sophisticated digital tools into traditional farming practices requires a steep learning curve and user-friendly applications tailored to vernacular languages.
4. **Data-Related Concerns:**

- **Data Privacy and Security:** Farmers express reluctance to share sensitive agricultural data due to concerns about privacy and security, as reflected in various studies.
- **Data Ownership and Access:** The question of who owns the vast datasets generated from the farm—the farmer, the platform, or the government—is a critical regulatory challenge that impacts farmer trust and willingness to participate.

5. **Small and Fragmented Land Holdings:** The typical Indian farm is very small (1-2 acres), and land leasing is common. This fragmentation makes the deployment of large-scale, fixed-position precision agriculture equipment financially and logistically unviable, necessitating portable, 'plug-and-play' hardware solutions.
6. **Resistance to Change:** Farmer reluctance to adopt new practices stems from a reliance on traditional methods, skepticism about unproven technology, and a lack of awareness regarding the potential economic benefits.

5.2 Policy Reorientation and Market Opportunities

Digitalization has catalyzed structural changes in agricultural policy, creating massive opportunities for growth.

- **Data-Driven Policy Implementation:** The direct income support schemes of the government, such as PM-KISAN, necessitated a reliable, digital farmer database. The unique biometric identifier, Aadhaar, has been pivotal in facilitating quick data collection and DBT implementation, transforming agriculture from a welfare sector to a more business-centric one.
- **Regulated Farming and Advisory:** The case of Telangana's Rythu Bandhu scheme shows the potential for linking income support to advisory services. The government guides farmers on crop choice based on digital analysis of supply, demand, and price forecasts. This *regulated farming* approach is made possible only by a robust digital database.
- **Marketing Reforms (e-NAM and Contract Farming):**
  - **Market Freedom:** Policies promoting the creation of an ecosystem where farmers and traders have the freedom to sell and purchase produce outside state-regulated market yards (mandis) facilitate efficient, transparent, and barrier-free inter- and intra-state trade. This opens the market for private players and digital channels to rationalize the value chain.
  - **Contract Farming:** A national framework for contract farming allows agri-business firms, processors, wholesalers, and exporters to engage directly with farmers. These entities can then support production using the latest technologies and digital advisory, ensuring quality and consistency.
- **The Power of FPOs:** The emergence of **Farmer Producer Organisations (FPOs)** is arguably the single largest opportunity for digital agriculture. FPOs act as a vehicle for consolidating farmers, their production, and their marketing efforts. They aggregate land, making the consolidated, bigger parcels suitable for technology rollout. This collective approach makes technologies like precision agriculture affordable and widely available for even the smallest farmer, creating a crucial win-win scenario for all stakeholders across the value chain.
- **Shared Economy Models:** Due to limited financial resources, **renting and sharing platforms** for high-cost agricultural equipment (tractors, harvesters), as pioneered by start-ups like EM3 Agriservices and Trringo, make eminent sense. Digital platforms facilitate a pay-per-use model, democratizing access to costly mechanization.

6. Empirical Study: Adoption Readiness in the Rayalaseema Region

A focused study of 200 farmers in the Rayalaseema region was conducted to investigate their readiness to adopt digital technology by analyzing the influence of gender and age on key adoption parameters.

6.1 Influence of Gender on Technology Adoption

The analysis reveals that gender significantly influences a farmer's interaction with technology **Interest in Learning:** The results indicate a higher percentage of **female farmers (58%)** are **highly interested** in learning about technology compared to male farmers (43%). However, the detailed breakdown of all interest levels (Highly interested, Interested, Somewhat interested, Not interested) suggests that the overall distribution of interest is significantly influenced by gender.

Chi-square value	p-value	Level of Awareness on Digital India				Total
5.858	0.119	Highly aware	Moderately Aware	Moderately unaware	Highly unaware	
Gender	Male	16	46	8	50	120
		13.30%	38.30%	6.70%	41.70%	100.00%
	Female	16	32	10	22	80
		20.00%	40.00%	12.50%	27.50%	100.00%
Total		32	78	18	72	200
		16.00%	39.00%	9.00%	36.00%	100.00%

- **Reliability on Technology:** There is a highly significant impact of gender on the opinion regarding the reliability of technology.
- **Accessibility of Authorities:** Female farmers report being satisfied or highly satisfied with the accessibility of authorities in need, compared to male farmers. However, the majority across both genders. Interest seems to be driven by factors other than age alone.

6.2 Synthesis of Empirical Findings

The empirical findings from Rayalaseema are critical:

1. **Gendered Adoption Gap:** The most pronounced gap lies in **technology reliability and trust**, where female farmers lag significantly, suggesting a need for specialized, trust-building, and hands-on digital training that addresses the specific needs and contexts of women in agriculture.
2. **Focus of Training:** The higher knowledge levels among older farmers (30-50 and >50 years) suggest that government and extension programs (like PM Gramin Digital Saksharata Abhiyan) have successfully targeted established landholders. However, this raises questions about outreach to younger, perhaps landless, farmers.
3. **Extension Service Failure:** High dissatisfaction with the accessibility of authorities across all demographics points to a critical bottleneck. The reorientation of traditional manpower-based extension services through ICTs (as intended by Krishi Vigyan Kendras and ATMA) is necessary to ensure that new digital information reaches the last mile effectively.

7. The Broader Socio-Economic Impact and the Path Forward

The successful integration of Digital India into agriculture promises a transformative socio-economic impact, leading to a more resilient and profitable sector.

7.1 Socio-Economic Benefits

- **Increased Productivity and Yield:** Precision farming techniques enabled by AI, IoT, and satellite imagery allow for optimized use of water, fertilizers, and pesticides. Case studies across India show that customized, localized recommendations in regional languages can boost yields by 20-40% in pilot projects. For instance, soil sensors and drone spraying have been shown to reduce water usage by 30-50% and cut chemical inputs by 40% through targeted delivery.

- **Enhanced Financial Inclusion:** DBT schemes like PM-KISAN, the use of Aadhaar for authentication, and platforms like Kisan Credit Card (KCC) and fintech solutions have increased the reliability of subsidies, improved credit access, and provided financial literacy tools.
- **Market Transparency and Fair Pricing:** Platforms like eNAM and direct market connectivity apps eliminate middlemen, ensure real-time price discovery, and facilitate transparent bidding, ensuring farmers receive better value for their produce.
- **Job Creation:** The rapid digitalization in farming is expected to create millions of new digital farming jobs by 2025, including precision agriculture specialists, drone pilots, data analysts, and mobile app agents/trainers. This not only boosts rural employment but also attracts talent back to the agricultural sector.

7.2 Conclusion and Recommendations

Digital India is a pivotal force redefining the socio-economic landscape of Indian agriculture. The government's strategic focus on creating a robust Digital Public Infrastructure (AgriStack, Krishi-DSS) is a world-class endeavor that promises to enhance governance, empower citizens, and drive innovation.

However, realizing the ultimate goal of transforming the lives of the *majority* of Indian farmers requires a sustained and multi-pronged approach to address the key barriers identified:

1. **Democratization of Cost:** Policies must focus on providing subsidies for **shared economy models** (e.g., equipment rental platforms) and the development of low-cost, plug-and-play hardware suitable for small, fragmented land parcels.
2. **Prioritizing Last-Mile Connectivity and Literacy:** The BBNL must accelerate rural broadband rollout. Concurrently, digital literacy programs (like PM Gramin Digital Saksharata Abhiyan) must shift towards **practical, vernacular-based, hands-on training**, with a specific focus on female farmers to bridge the reliability and access gap.
3. **Strengthening Extension Services:** The traditional extension system needs a robust infusion of ICTs and must integrate with new digital platforms like Krishi-DSS and m4Agri. Authority accessibility must improve, ensuring that the digital delivery of services and grievance redressal is seamless and effective.
4. **Harnessing FPOs:** FPOs must be strategically positioned as the primary interface for technology adoption and market linkage, leveraging the power of aggregation to make high-cost precision agriculture feasible and affordable for their members.

The commitment to digital transformation, coupled with strategic efforts and addressing the on-ground challenges faced by farmers in regions like Rayalaseema, will ensure that Digital India successfully positions the nation at the forefront of the technological revolution, fostering a brighter, more connected, and prosperous future for the millions who depend on the soil.

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