Machine Economy – The New Frontier of Digital Transformation in IoT

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1 INTRODUCTION

Digital transformation has taken the world by storm over the last five years. Any enterprise or industry could not avoid asking "What does digital transformation imply for us?" The answers to this question usually revolve around adopting technologies that have become mature and mainstream to create new or modify existing business processes and customer engagement strategies.

Digital Transformation in industries goes by different names, such as Industrie 4.0 (Germany), Industrie du futur (France), Made in China 2025 (China), or Smart Manufacturing (US), to name a few. Over the past few years, the convergence of artificial intelligence, blockchain, cloud computing, edge computing, Internet of Things (IoT), 5G, computer vision and augmented/virtual reality have been supporting the creation of even more and more complex Digital Twins. While every progress in these technologies is pushing the digital twins closer to their real-world counterpart, these are also driving the industry through the next wave of the digital revolution.

Although the rapid growth of IoT in consumer and industrial markets is driving society's ongoing digital transformation and datafication [1]in many amazing ways, today's IoT businesses, like other dominant Web2 platforms, are primarily built upon centralized infrastructures and fully managed by enterprises. Such a centralized approach, while enabling enterprises to maximize its business value extraction and advantaging the biggest players, is more and more questioned by public opinion and governments, especially in light of the latest geopolitical events. Data governance, ownership, and sovereignty threaten the business models on which big players have been thriving so far. The introduction of blockchain and Web3, i.e., the third iteration of the internet, provides new perspectives and growth opportunities for IoT businesses by realizing the so-called machine economy.

In this article, we introduce the emerging machine economy and explain why it is becoming a new frontier of digital transformation in IoT from both technology and business aspects. We also discuss several machine economy use cases in practice. The rest of the article is as follows: Section 2 defines the machine economy and describes its key enablers and success factors. Section 3 presents three machine economy-oriented business models. Section 4 discusses several existing and ongoing machine economy use cases. Finally, the article concludes in Section 5.

2 MACHINE ECONOMY

In this section, we first introduce the machine economy and then describe the three key enabling technologies behind it. In the last part, we discuss the machine economy's key success technology and business factors.

[1] https://en.wikipedia.org/wiki/Datafication

2.1 WHAT IS THE MACHINE ECONOMY?

According to Next Big Thing AG [1], the machine economy is a network of smart, connected, and economically independent devices and machines acting as autonomous market participants, executing economic transactions and other activities with little to no human intervention. This definition shows the potential disruption factors the machine economy brings to IoT. On the one hand, the machine economy addresses the traditional manufacturing and business processes in place in most enterprises and industries. On the other hand, it leverages technologies that enable autonomous transactions between devices or machines.

2.2 KEY ENABLERS OF THE MACHINE ECONOMY

Three key aspects namely enable the machine economy: the Internet of things (IoT), distributed ledger technology (DLT), and token economics. The relations between the three key enablers are shown in Figure 1.

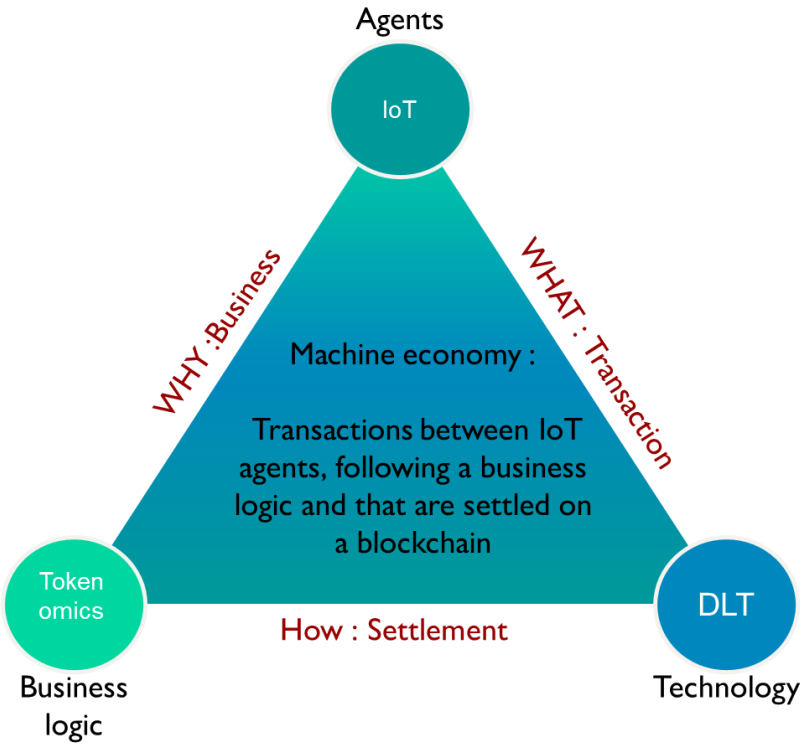

Figure 1 : The three key enablers of the machine economy

2.2.1 THE INTERNET OF THINGS (IOT)

The explosion of smart IoT devices has allowed people and machines to communicate and exchange information anywhere at anytime. Besides consumer-oriented applications, various smart sensors have been integrated into industrial machines to improve factories' manufacturing processes. All IoT devices are poised to provide real-time information regarding the associated

objects in the physical world. Once tokenized[1], the IoT devices and generated data can create marketplaces of physical and digital assets. Those assets can then be indexed, searched, and traded as other online commodities.

2.2.2 DISTRIBUTED LEDGER TECHNOLOGY (DLT)

A distributed ledger can be described as a digital ledger of asset transaction records maintained decentralized across different locations and people. The salient characteristics of a distributed ledger — decentralization, transparency, immutability and trustworthiness — make it a good infrastructure for (mutually) untrusted parties conducting business without relying on any trusted intermediary like a bank or institution. More importantly, DLT has introduced an element of finite supply when physical or digital assets are tokenized, thereby transforming those assets into the "Internet of Value".

2.2.3 TOKEN ECONOMICS

According to [2], token economics, otherwise called crypto economics or tokenomics, can be understood as a subset of economics that studies the economic institutions, policies, and ethics of the production, distribution, and consumption of goods and services that have been tokenized. In the context of machine economy, token incentives represent a powerful mechanism to address the cold start problem in IoT businesses and well-designed economic incentives. Token distribution models are crucial for influencing the behaviors of all the IoT ecosystem stakeholders and determining the long-term sustainability of an IoT business.

2.3 KEY SUCCESS FACTORS OF THE MACHINE ECONOMY

The previous section explained the three fundamental building blocks for realizing a machine economy-oriented system. However, building a thriving and sustainable machine economy depends on several critical success factors, detailed from both technology and business perspectives.

2.3.1 TECHNOLOGY PERSPECTIVE

- **Trustworthiness of IoT systems**: IoT devices and the generated data are assets in the machine economy. As a result, the industry best practices [3][4] should be applied to ensure the end-to-end trustworthiness of the IoT stack. IIC [3] defines trustworthiness as "The degree of confidence one has that the system performs as expected. Characteristics include safety, security, privacy, reliability and resilience in the face of environmental disturbances, human errors, system faults and attack". Therefore, guaranteeing the trustworthiness of IoT systems requires applying industry standards to the end-to-end process from the data collection, processing and transmission, and to the life cycle management level with device onboarding, updates and decommissioning. Only with such standards, can marketplaces with valuable IoT-driven assets be achieved.

[1] Asset tokenization is the process by which an issuer creates the digital representation (a.k.a. a crypto token) of a tangible or intangible asset on a distributed ledger.

- **Security, Privacy and Scalability of DLT systems**: DLTs provide decentralized financial market infrastructures for tokenizing, trading and settling asset transactions. The security of assets and transactions is paramount and should be carefully implemented [5]. Applications with privacy concerns should apply certain privacy-enhancing technologies such as homomorphic encryption[1] (HE), zero-knowledge proof[2] (ZKP), secure multi-party computation[3] (MPC), and confidential computing[4] (CC). Moreover, the scalability of DLTs should be properly addressed to accommodate the large volume of transactions from IoT devices.

2.3.2 BUSINESS PERSPECTIVE

The machine economy represents the new paradigm shift in IoT-related businesses. The more the IoT stack has a predominant position in the business model, the more significant the disruption can be. To embrace the machine economy successfully and build a reliable and sustainable position in the future, business owners should consider the following factors:

- **Fairness and transparency of business models**: The fair and transparent distribution of business values among all the value chain stakeholders is the key to building a thriving machine economy. It should be able to align the stakeholders' benefits, and encourage participation in the ecosystem to create the flywheel effect.
- **Effectiveness of customer engagement strategies**: An effective customer engagement strategy is important to increase customer stickiness and loyalty. Emerging Web3 technologies such as Decentralized Finance[5] (DeFi), Non-Fungible Tokens[6] (NFTs), and Decentralized Autonomous Organizations[7] (DAOs) provide a set of tools for building innovative and robust customer engagement strategies in the machine economy. While DeFi could be leveraged to increase inclusivity in global supply chains [6], NFTs, for example, have become popular choices by brands for enhancing their customer relations programs [7] but also as a new way to address IP protection issues when data are flowing between multiple stakeholders. DAOs, on the other hand, aim to offer customers an opportunity to participate in the decision process of certain brand-building activities [8].
- **Robustness of token economy models**: A robust token economy model is critical for incentivizing all the stakeholders in a machine economy ecosystem to continue participating business activities, thereby ensuring the long-term sustainability and steady growth of IoT businesses.

[1] *https://en.wikipedia.org/wiki/Homomorphic_encryption*
[2] *https://en.wikipedia.org/wiki/Zero-knowledge_proof*
[3] *https://en.wikipedia.org/wiki/Secure_multi-party_computation*
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3 MACHINE ECONOMY-ORIENTED BUSINESS MODELS

As noted in recent articles [9][10] on Forbes, the emerging machine economy unlocks new opportunities for conventional IoT businesses to redefine their value propositions and customer engagement strategies. This section describes several new business models inspired by the machine economy.

3.1 MACHINE-AS-A-SERVICE (MAAS)

As valuable assets in the physical world, machines come with certain utilities and can fulfil specific tasks. Machine owners could create a machine-centric business in the machine economy in the following ways:

- **Jointly building a machine network**: A group of machine owners could jointly build a machine network (e.g., a LoRaWAN or 5G network) in a decentralized manner to provide certain functionalities to the public. The machine owners will be paid based on the predefined rules whenever a customer uses the machine network.
- **Jointly owning a machine**: A group of people could form a machine DAO and jointly own a machine (e.g., an expensive industrial machine). The revenue generated by the machine will then be distributed to all the stakeholders based on the predefined rules as specified in the machine DAO.

Note that the above two business models enable a community-driven approach to building IoT businesses, which could help organizations reduce the cost of deploying an IoT solution.

3.2 SENSING-AS-A-SERVICE (S^2AAS)

An IoT device's most important utility is collecting data from the attached physical object. The collected data is typically sent to a centralized backend processing system for extracting insights that will help IoT business owners make decisions.

With the machine economy, the device owners could leverage DLT to create decentralized marketplaces to share data with interested third parties in a peer-to-peer manner, as illustrated in Figure 2. Such a business model enables device owners to earn passive income by sharing their device data via a decentralized marketplace, thereby having great potential for customer growth. In particular, device owners fully control device data sharing in this case.

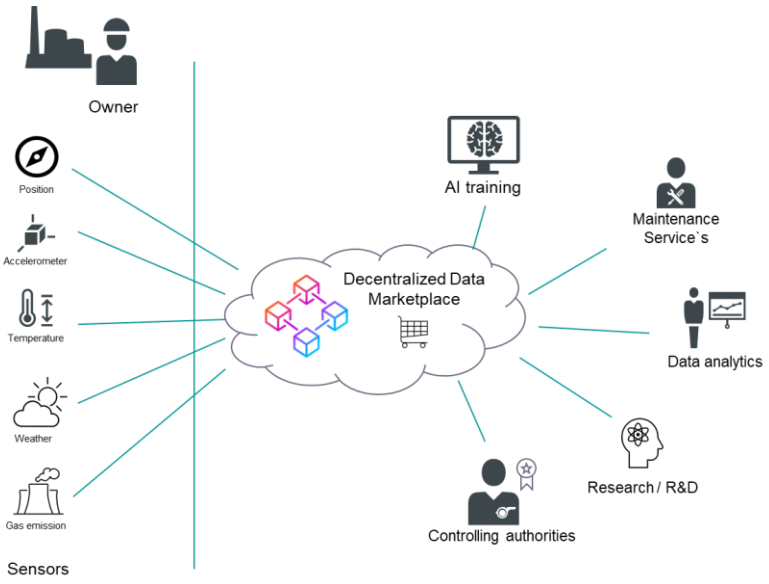

Figure 2 : Sensing-as-a-service and monetization of data

3.3 ASSET TOKENIZATION

In the machine economy, a distributed ledger for trading and exchanging makes the machine and generated data tokenization possible. For example, a machine could be tokenized as NFTs on the distributed ledger and each NFT represents a fractional digital ownership of the machine in the physical world. Moreover, NFT holders could be granted certain rights (e.g., use the machine for a certain amount of time per week) by the owner of the machine. In addition, NFTs can be freely traded in a marketplace for ownership transfer. Such a business model provides a flexible and effective approach to customer engagement and mitigates the illiquid nature of expensive assets.

3.4 PAY-PER-USE

In process industries, many industrial sensors measure the raw material levels in silos. These sensors can be connected to the blockchain, automating the payment process altogether. The variation of raw material triggers a smart contract on the blockchain, which calculates the quantity consumed, retrieves the agreed price, and autonomously settles the transaction on the blockchain. The supplier does not wait for the end-of-the-month reconciliation to be paid, and the end-user does not bear any inventory-management-related costs. By synchronizing the goods and the financial flows [11], this application demonstrates how the machine economy improves cash flow by shortening the payment cycles, eliminating costly reconciliation processes, and sustainably optimizing the working capital.

3.5 TRUSTED DATA AND DATA ORACLE

Many industries are subject to regulations and compliance regarding their production parameters, especially the waste and the output of the industrial process. They must provide data to certified organizations or public entities. Those data are mostly related to public health and are usually measured by Industrial IoT devices. In a machine economy context, authorized users have access to the data and control their authenticity directly on the blockchain without needing to investigate the IT infrastructure to ensure that data have not been tampered with. Additionally, such IoT equipment publishing data directly on the blockchain could turn into an industrial or environmental data oracle, usable by any smart contracts on the blockchain.

4 USE CASES AND OPPORTUNITIES – THE MACHINE ECONOMY IN ACTION

In this section, we describe several ongoing and emerging consumer and industrial-oriented use cases of machine economy.

4.1 X-TO-EARN

X-to-Earn is a generic business model powered by blockchain and Web3 technologies where users can earn cryptocurrency rewards by participating in a range of activities. The X-to-Earn model has shown great potential to transform how people engage with machines, especially when monetizing the machine utility and collected data. In the context of machine economy, users have been incentivized to:

- Deploy a global-scale, public LoRaWAN network [12];
- Deploy a global-scale, public mobile network [13] [14];
- Deploy a smartphone-powered network for connecting Bluetooth devices [15];
- Build a community-owned mapping network via dash cameras [16];
- Deploy a global-scale, public weather station network [17];
- Change their lifestyle and exercise and move outdoors every day [18];
- Share their wearable data to third-party service providers [19].

These use cases have demonstrated that it is highly viable to incentivize communities to complete specific machine-related tasks by leveraging well-designed token economic models.

4.2 FRACTIONAL OWNERSHIP

Fractional ownership fosters collaborative consumption in which a group of owners split the overall cost of owning an asset, as explained in section 3.3 In the context of machine economy, a group of users could utilize the blockchain to tokenize a physical machine and share the benefits returned by the machine. Such an approach unlocks the opportunity for individuals to own an expensive physical machine jointly and enables machine manufacturers to grow their customer base and tap into additional revenue streams.

In practice, several companies have explored this direction. For instance, the fractional ownership program set up by Ocean Falls Blockchain [20] allows their customers to rent hashing

powers in quantities of one-tenth the cost of an individual mining machine. In another example, Ahoy LLC [21] and IoTeX [22] are applying the concept of fractional ownership to an Industry IoT Consortium test drive [23] that aims to facilitate boat owners to monetize underutilized resources, stagnant occupancies, and user data globally.

4.3 TRUSTED AND TRANSPARENT ASSET TRACKING IN SUPPLY CHAINS

A lack of transparency, integrity, and availability of supply chain data has plagued its operations and made collaboration among stakeholders very difficult. To address these industry-wide challenges, the Industry IoT Consortium test drive [24] initiated by IoTeX [22] combines tamper-proof hardware and blockchain software to create a trusted and transparent asset-tracking solution for valuable assets within a medical facility or among entities of a healthcare network.

In the test drive, secure edge devices capture the real-time status (e.g., location, temperature, humidity, etc.) of physical assets when the freight carrier network is moving them. The asset status is then sent to a smart contract on the blockchain for service level agreement (SLA) validation. Given an SLA breach, the stakeholders involved in that SLA see penalties automatically settled[25]. Using machine data and blockchain to coordinate and automate the business process has shown great potential for improving supply chain efficiency and user experience and reducing business expenses.

4.4 INDUSTRIAL METAVERSE

Industrial Metaverse is an emerging trend that targets combining immersiveness, real-time data and digital twins to create new business models and accelerate digitalization. One of the puzzle pieces of Industrial Metaverse will be connecting the edge devices and trusted data flow with the digital twins to create near real-time simulation and prediction for real-world situations [26]. To enable ecosystem-based participation and growth of the Industrial Metaverse, it will be important to incentivize network participants.. This incentivization could be for data sharing, verifying the origin or authenticity of components, designs and assets, or creating new ones within the metaverse. Enabling edge devices to directly participate in the incentivization mechanism would create further autonomy and highly efficient digitalization use cases.

5 CONCLUSIONS

In this article, we introduced the machine economy, a new frontier of digital transformation in IoT. We have explored why IoT and DLT are key and complementary technologies that will enable the growth of the machine economy and unlock new opportunities for IoT manufacturers and end-users. We described some of the disrupting business models that the industry is witnessing and provided tangible examples of their implementation.

The combination of web2 companies with their significant footprint in the IoT markets and the vibrant, ultra-dynamic environment of web3 creates the perfect ground for significant disruption. While there are challenges to be addressed, we are undoubtedly entering a new era where IoT and machine economy will shake the status quo for both IoT manufacturers and IoT users. In this context, once again speed of adoption will be once again the main driver for success.

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