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A Practical Analysis of Digital Transformation and Supply Chain Governance Jointly Advancing Sustainable Development

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ABSTRACT

As digital technology continues to empower the real economy and dual-carbon policies are fully implemented, traditional extensive supply chain management models in manufacturing can no longer meet the practical demands of green and low-carbon industrial transformation. Issues such as fragmented information across the industrial chain, lagging regulation, and unclear responsibilities directly hinder the pace and quality of low-carbon development in manufacturing. To achieve sustainable development in manufacturing supply chains, end-stage remediation alone is insufficient; the key lies in integrating digital technologies with supply chain governance systems to enhance green development from the source. This paper takes the actual operation of manufacturing supply chains as its research subject, combining field survey data with publicly available industry statistics. Moving beyond single-focused studies on either technology or institutions, it emphasizes analyzing the interplay between digitalization and supply chain governance. The study identifies four core challenges in current industrial transformation: significant disparities in digital capabilities among different market players, lack of unified green governance standards across industries, loopholes in value distribution mechanisms along the industrial chain, and insufficient integration between technology and institutional frameworks. Research reveals that digital technologies can address various technical shortcomings in traditional supply chain governance, while standardized governance systems can clearly define the scope of digital technology application. When working in tandem, these two elements can establish a modern, closed-loop supply chain governance system covering the entire process. Addressing practical industry challenges, this paper proposes several actionable optimization strategies, offering practical theoretical references and real-world insights for advancing green upgrades and building long-term governance systems in manufacturing supply chains.

KEYWORDS

Digital transformation; Supply Chain Governance; Sustainable development; ESG; Industrial Chain Collaboration

1. INTRODUCTION

Nowadays, the domestic digital infrastructure is continuously improving. Mature digital technologies such as the Internet of Things, big data, and blockchain have been fully integrated into various aspects of manufacturing, including production, warehousing, logistics, and energy consumption control. They have become the core driving force for improving industrial quality and efficiency and promoting industrial transformation and upgrading [1]. With the continuous refinement and implementation of the dual-carbon policy, green development is no longer just a macro policy requirement but a mandatory rule that every manufacturing enterprise must abide by in its daily operations. For manufacturing enterprises, doing a good job in the green and intelligent upgrading of

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the supply chain is the necessary path to stabilize their market competitiveness and achieve long-term stable development.

For a long time in the past, domestic manufacturing mainly relied on expanding production capacity and increasing scale to enhance economic benefits. This kind of extensive development approach not only rapidly expanded the industrial scale but also left various problems such as high energy consumption, high pollution, and loose management. The traditional production and supervision models have been unable to keep up with the current pace of high-quality development. Now, the development logic of the industry has completely changed. The simple model of relying solely on scale expansion has gradually been eliminated by the market, and new development models such as green and efficient, intelligent and efficient, and standardized and orderly are reshaping the industrial ecosystem and competition pattern of the entire manufacturing industry [2].

The manufacturing supply chain involves a large number of enterprises, a wide coverage, and complex interests. The effect of supply chain governance directly affects the overall effectiveness of regional manufacturing green development. With the gradual popularization of intelligent and refined management models, the traditional governance methods relying on manual investigation, post-event accountability, and contract constraints have exposed many drawbacks, such as slow information update, fragmented management, and lack of risk prediction. I believe that the biggest problem with traditional supply chain governance is that it only focuses on post-event rectification, lacks pre-event prevention and dynamic supervision throughout the process, which is also the main reason why the green transformation of most manufacturing enterprises is unstable and difficult to sustain over the long term.

The popularization and application of digital technologies have provided new ideas for solving various problems in traditional supply chain governance. Digital platforms have functions such as real-time monitoring, full traceability, intelligent analysis, and data summarization, which can fully meet the actual needs of green and refined governance. However, from the perspective of the entire industry, the digital transformation of most enterprises is relatively superficial. They only simply update equipment and launch systems, without integrating digital tools with core tasks such as green control, ESG compliance, and low-carbon operation. This leads to the failure to truly realize the green value of digitalization, and the industry generally has high investment costs, poor governance effects, and digitalization being merely formalism [3].

Most of the relevant research in the domestic academic circle mainly analyzes the enabling role of digital technologies or the optimization of governance systems separately. There are few studies that deeply analyze the combination logic of technology and systems, as well as the collaborative operation mode. The overall research perspective is relatively single, and has limited guidance for the actual operation of enterprises. Based on this research gap, this paper combines first-line industry research data and practical experience to construct a two-way research framework of technology empowerment combined with system constraints, systematically analyzes the linkage mechanism, actual obstacles, and optimization paths of the two, and obtains research conclusions that are in line with the actual development of the manufacturing supply chain.

2. THE COLLABORATIVE COUPLING MECHANISM OF DIGITAL TRANSFORMATION AND SUPPLY CHAIN GOVERNANCE

2.1. Digital Technology Fills The Shortcomings and Weaknesses of Traditional Supply Chain Management

The domestic manufacturing supply chain mostly adopts a decentralized layout across regions and enterprises. This layout can refine industrial division of labor and optimize resource allocation, but it also makes the overall green governance coordination management more difficult. Industrial

concentration parks can achieve unified standardized management, while the decentralized supply chain management points are scattered and coverage is incomplete, making it impossible to achieve unified supervision across the entire area. This is an important reason for the low efficiency of traditional supply chain governance.

Before the widespread adoption of digital technology, industry green governance mainly relied on annual centralized inspections, enterprises' self-reporting of data, and post-violation accountability and punishment. Key governance data such as carbon emissions, energy consumption, and pollutant discharge were all based on manual statistics, accounting, and archiving. Manual operations were not only costly and inefficient, but also prone to irregular behaviors such as data errors, duplicate reporting, and human tampering. The incomplete data management method led many enterprises to engage in "greenwashing" behavior [4]. Some enterprises used to modify business data, falsely report emission reduction achievements to evade supervision, which disrupted the normal market order of supply chain green development.

The continuous upgrading and comprehensive application of digital technology have fundamentally changed the traditional manual governance model and effectively filled the various shortcomings of traditional supply chain governance. Internet of Things devices can collect real-time data of the industrial chain operation, ensuring the authenticity and validity of governance data; blockchain technology, relying on the characteristics of data immutability and full traceability, has built a reliable industrial data credit system; big data technology can integrate massive and multi-dimensional industrial data, providing precise support for enterprises to optimize governance plans and make business decisions. The combined use of various digital technologies has laid a solid technical foundation for the green, refined governance of the supply chain [5].

The digital practices of major manufacturing enterprises have directly demonstrated the governance value of digital technology. The integrated digital control platform established by enterprises has broken through the long-standing information barriers in the industrial chain, solved long-standing problems such as lagging industry supervision, difficult traceability of responsibilities, and cumbersome review processes, and built a complete basic framework for intelligent, refined, and green governance of the supply chain.

2.2. Regulation of Institutional Norms for the Implementation of Digital Technologies in Practical Applications

Digital technology is merely a tool to facilitate industrial upgrading. It does not possess the functions of green constraints and governance on its own. Simply updating equipment and upgrading technologies cannot directly drive the sustainable development of industries. Currently, many manufacturing enterprises have misconceptions, simply equating the upgrade of digital equipment with green transformation. Eventually, problems arise where the digital investment and green governance do not match. Without institutional constraints, simple technological upgrades can only slightly improve the operational efficiency of enterprises, and fundamentally cannot achieve core green development goals such as energy conservation, carbon reduction, resource saving, and compliant operation [6].

The industry lacks unified governance standards and incomplete internal supporting mechanisms, which are the key reasons for the ineffectiveness of digital transformation and the failure of technology empowerment. Without institutional constraints, digital construction can easily lead to issues such as technology abuse, equipment idleness, and data leakage, significantly reducing the actual benefits of digital transformation for enterprises. Such problems are particularly prominent in small and medium-sized manufacturing enterprises. Many of these enterprises blindly follow trends to carry out digital transformation, but fail to simultaneously establish corresponding green governance systems, ultimately resulting in digital resource waste and failing to fully achieve governance effects.

A well-established supply chain governance system can clearly define the usage scope and execution standards for digital technology, avoiding disorderly application of technology. Standardized supplier admission rules, dynamically updated ESG assessment systems, clear division of rights and responsibilities between upstream and downstream, and strict penalty mechanisms for violations can form a governance synergy with digital technology [7]. Integrating ESG requirements such as green production, low-carbon emission reduction, resource recycling, and social responsibility into the digital operation system can change the single attribute of digital tools only enhancing efficiency, and comprehensively promote the green upgrade of the industrial chain, helping the industry achieve growth in economic, ecological, and social benefits simultaneously.

2.3. The Two Work Together To Build A Complete Chain of Sustainable Governance Loop

Digital transformation and optimization of supply chain governance are not simply additive relationships; they are mutually supportive and complementary as a whole. Relying solely on technological empowerment without institutional constraints will lead to governance chaos and resource waste; relying solely on institutional control without technological support will result in difficulties in implementing governance and superficiality. A single development model cannot achieve long-term stable governance of the supply chain.

The comprehensive establishment of the digital system has completely changed the governance logic of the supply chain. The traditional model only focuses on post-event remediation, while the digital model can achieve full-cycle governance through pre-event warning, in-process control, and traceability throughout the process, significantly improving the accuracy and efficiency of supply chain governance [8]. Standardized governance systems have clarified the operational rules and development directions for digital transformation, effectively avoiding issues such as technology abuse, data chaos, and resource idleness, and enabling the digital construction to proceed in a compliant and stable manner.

The deep integration of technology and institutions, as well as the two-way empowerment, can build an all-encompassing and closed-loop operation of the industrial chain governance system. The Walmart fresh produce blockchain traceability project is a relatively classic case of green governance of the supply chain in the industry. The enterprise uses blockchain technology to achieve full-process traceability of fresh produce, while also providing a complete set of supplier assessment, accountability, reward, and punishment systems, ensuring that the technology implementation has standards, data control has norms, and responsibility is implemented with targets [9]. This case clearly demonstrates that technology empowerment combined with institutional constraints can achieve precise control of all parties and all links of the supply chain. This model can fully adapt to the green upgrade work of domestic manufacturing supply chains.

3. THE ACTUAL PREDICAMENT OF PROMOTING SUSTAINABLE DEVELOPMENT THROUGH THE COORDINATED ADVANCEMENT OF DIGITALIZATION AND SUPPLY CHAIN GOVERNANCE

3.1. The Digital Capabilities of Enterprises Vary Significantly, And There Are Obvious Gaps in Governance Coverage

The digital upgrading of domestic manufacturing industries shows a clear two-tiered differentiation pattern. Leading enterprises in the industry have abundant funds, professional talents, and profound technological accumulation, and have basically established integrated digital control platforms, achieving intelligent, refined, and green management of the core links of the supply chain. Their transformation effects are very prominent.

Small, medium, and micro supporting enterprises are the main body for ensuring the stable operation of the supply chain, accounting for the vast majority of the industry. However, these enterprises generally have weak business foundations, tight funds, and lack of digital professionals and technical reserves. They are unable to bear the high costs of building digital systems, purchasing equipment, and maintaining platform operations on a daily basis, and are difficult to adapt to the standardized digital supply chain systems built by leading enterprises. The digital capabilities gap between upstream and downstream enterprises has led to obvious structural breaks in the green governance of the industrial chain, making it impossible to form an all-encompassing integrated governance pattern [10].

At present, the green governance systems of leading enterprises mostly cover only the first-level core suppliers. A large number of downstream small, medium, and micro enterprises are excluded from the digital governance system, resulting in large areas of governance gaps. The 2024 supply chain ESG research data from Deloitte clearly reflects this issue. Over 90% of large domestic manufacturing enterprises have included green constraints in their procurement contracts, but due to the weak digital foundation of small and medium-sized enterprises, unstandardized data reporting, and incomplete internal governance, more than half of the green clauses cannot be implemented. There are always significant shortcomings in the overall green governance of the industrial chain.

3.2. The Absence of Industry-Wide Standards and The Prevalence of Data Silos Are Common Issues

At present, there is no unified standard for supply chain carbon accounting, energy consumption statistics, ESG evaluation, and information disclosure applicable to the entire manufacturing industry in China. The statistical methods and evaluation rules used by various sub-sectors and enterprises are all different. There is a lack of authoritative and unified implementation basis for industry governance, which is also the deep-seated reason why technology and systems cannot be deeply integrated.

The digital control platforms independently built by major enterprises have different port compatibility, data formats, and statistical logic, and cannot be intercommunicated. The industry has not yet formed a universal standardized operation specification [11]. This fragmented industry situation has greatly increased the operational pressure on small and medium-sized suppliers. Small and medium-sized enterprises need to connect with multiple cooperating enterprises and repeatedly complete the same tasks such as data filling, calculation, and upload, which not only increases manpower and operational costs but also reduces the governance efficiency of the entire industrial chain.

The lack of industry standards further exacerbates the problem of data islands in the industrial chain. Currently, the data sharing and circulation mechanism across regions, enterprises, and industries is not perfect. Core industry data such as energy consumption, carbon emissions, and green governance are disconnected and cannot be intercommunicated. The value of massive industrial data cannot be effectively mined, which significantly weakens the enabling effect of digital technology. At the same time, the absence of a unified evaluation standard provides opportunities for some enterprises to operate illegally. Some enterprises manipulate data and falsely report emission reduction achievements to disguise green operations, disrupting the fair competition order of the industry and increasing the difficulty of market supervision.

3.3. Data Security Issues and Uneven Distribution of Benefits, Along With Low Enthusiasm for Enterprise Collaboration

The core of industrial chain collaborative governance lies in achieving cross-enterprise data interoperability and resource sharing. However, core operational data such as production capacity, energy consumption, pollution discharge, and business performance are all commercial secrets of enterprises, directly affecting their market competitiveness. In my opinion, most small and medium-

sized enterprises are reluctant to actively open up their data and participate in collaborative governance. The most fundamental concern is the fear of data leakage and damage to their own interests, which is also the main reason for the slow progress of supply chain collaborative governance.

The problem of mismatch between industrial chain costs and benefits further reduces the enthusiasm of small and medium-sized enterprises for transformation. In the current industrial chain structure, all transformation costs such as digitalization transformation, system operation and maintenance, talent training, and green rectification are borne solely by small and medium-sized suppliers. However, the policy dividends, brand advantages, and cost reduction benefits brought by digital and green governance are mostly occupied by leading enterprises. The severe imbalance between investment and returns has completely deprived small and medium-sized enterprises of the motivation to actively transform and cooperate in governance [12].

Affected by the above factors, most small and medium-sized enterprises merely complete basic compliance work passively and will not actively invest funds and human resources in digitalization upgrades and green renovations. The combination of multiple problems such as the lack of data security guarantees, imbalance in benefit distribution, and unclear rights and responsibilities of enterprises has prevented the formation of a virtuous industrial ecosystem for upstream and downstream collaboration governance and made it difficult to implement regular and long-term collaborative governance in the supply chain.

3.4. The Integration of Technology and System is Relatively Shallow, And There is a Problem of Development Disconnection

The entrenched departmental barriers and division of responsibilities within enterprises are the core reasons why the integration of technology and system fails to reach a substantive level. Most manufacturing enterprises have not established a regular cross-departmental collaboration mechanism, and each business segment operates independently with poor communication, directly leading to the separate advancement and disconnection of digitalization construction and green governance [13].

The technical departments of enterprises fully take charge of digitalization construction, with their work focus solely on system setup, equipment upgrade, and functional optimization, largely ignoring the actual business needs of green control, low-carbon governance, and ESG compliance. Meanwhile, the tasks of green governance, environmental rectification, and compliance management are solely handled by the administrative compliance department, which does not participate in the design and optimization of the digital platform throughout the process. The complete segmentation of business segments has made the digital platform mainly serve operational work such as order management, logistics scheduling, and cost accounting, while the sustainable development functions such as green production, carbon emission control, and resource recycling are severely lacking.

The simplistic management thinking that only focuses on post-event rectification further exacerbates the disconnection between technology and system. Most enterprises have been using the outdated management model of centralized annual review, post-event accountability and rectification, and retention of materials for archiving, which wastes the real-time monitoring, intelligent warning, and full traceability features of the digital system, and fails to convert technological advantages into actual governance effects [14]. The dual problems of formalized technology application and rigidized system management directly lower the overall comprehensive governance level of the entire supply chain.

4. DIGITALIZATION AND SUPPLY CHAIN GOVERNANCE COLLABORATIVELY EMPOWERING THE OPTIMIZATION PATH FOR SUSTAINABLE DEVELOPMENT

4.1. Carry Out Digital Transformation in a Hierarchical Manner to Narrow The Digital Gap in the Industrial Chain

The digitalization of the industrial chain showing two extremes is a long-standing structural industry problem. Uniform and template-based transformation plans have extremely poor adaptability and are not suitable for all enterprises to implement. By stratifying and advancing the digitalization upgrade based on enterprises' resource reserves, financial strength, and technical level, it is possible to steadily narrow the digital gap in the industrial chain and achieve coordinated development of the entire industrial chain.

The leading enterprises are the core hubs of the industrial chain, possessing sufficient technology, funds, and industry resources. They should not only focus on their own digitalization construction. Head enterprises need to actively play a leading role in the industry by optimizing platform connection ports, developing low-cost and lightweight access modules, and simplifying upstream and downstream connection processes, etc., to reduce the technical barriers and financial pressure for the digital transformation of small and medium-sized suppliers, and promote the synchronous digitalization upgrade of the entire industrial chain through the model of large enterprises leading small enterprises [15].

The precise support from the government is the key for small and medium-sized enterprises to break through the predicament of digital transformation. Support policies such as financial subsidies, technical assistance, public welfare training, and project empowerment can precisely address the pain points of small and medium-sized enterprises, such as insufficient funds, shortage of talents, and weak technology, and lay a solid foundation for the digital development of small and medium-sized enterprises. The supply chain governance model of Ideal Motors in the new energy vehicle industry is worthy of industry reference. The enterprise integrates all levels of suppliers into a unified digital control system, combines with a complete green reward and punishment mechanism, and realizes the refined management of the supply chain process, providing a mature practical case for the layered promotion of green supply chain upgrading in traditional manufacturing.

4.2. Unify Industry Data Standards and Build A Shared and Governed Digital Platform

The disorderly industry data standards and the difficulty in cross-enterprise data circulation are the fundamental problems that hinder the deep synergy between technology and systems. To fundamentally enhance the effectiveness of collaborative governance in the industrial chain, it is necessary to break the situation where enterprises operate independently and establish a unified, common and standardized standard system and sharing platform across the entire industry. The rules for data circulation must be clarified, and a solid institutional foundation for cross-enterprise and cross-chain collaborative governance must be laid.

The industry association can take the lead, in collaboration with leading enterprises and research institutions, based on the production characteristics, operation processes and governance difficulties of each specialized industry, to formulate corresponding green governance norms for the supply chain [16]. The standardization of carbon footprint accounting, energy consumption statistics, ESG evaluation and information disclosure should be unified, so that industry governance work has rules to follow and evidence to rely on. Each region can rely on existing government resources to build regional supply chain digital public service platforms, integrate core data such as enterprise compliance, energy consumption and emission reduction, and open up cross-entity data sharing

channels, reducing inefficient work such as repeated filling out and repeated review by enterprises, and improving the overall governance efficiency of the industry.

By building a governance mechanism with full-process traceability and intelligent verification based on blockchain technology, it is possible to curb the chaos of "greenwashing" by enterprises from the source and ensure the authenticity and credibility of industrial data. The original data of enterprises' green development is fully traceable and can be verified at any time, eliminating illegal behaviors such as data tampering and false reporting at the technical level. High-quality industrial data with unified standards and traceability can not only enhance the credibility of green governance in the industry, but also provide reliable data support for policy optimization, enterprise rating and industrial structure adjustment [17].

4.3. Optimize the Mechanism of Rights, Responsibilities and Interests, And Activate The Internal Collaborative Driving Force of Enterprises

Relying solely on policy calls cannot completely solve the problem of low willingness of small and medium-sized enterprises to collaborate in governance. To build a long-term co-governance industrial pattern, it is necessary to address core issues such as imbalance of power and responsibility, unequal benefits, and insecure data at the mechanism level, eliminate the concerns of small and medium-sized enterprises regarding participation, and activate the internal driving force for collaborative governance within the industrial chain.

The industry needs to clearly define the data usage rights and responsibility boundaries of various market entities, clearly distinguish the applicable scopes of confidential business data, core operating data, and public governance data, so as to avoid security risks caused by excessive data openness and prevent governance failure due to data isolation [18]. Enterprises themselves need to improve security protection measures such as data encryption, hierarchical permissions, and traceability and accountability, build a data security defense line, and effectively protect the data rights of small and medium-sized enterprises, eliminating their concerns about transformation.

The industrial chain needs to restructure a favorable distribution pattern of interests, establish a collaborative mechanism of cost sharing, benefit sharing, and risk sharing, and change the current imbalance situation where small and medium-sized enterprises bear the transformation costs alone and leading enterprises monopolize the development benefits. Leading enterprises can leverage their resource advantages and provide technical assistance, preferential orders, and resource sharing to enable small and medium-sized enterprises to truly enjoy the benefits of green digital transformation. At the same time, the industry needs to improve a two-way reward and punishment mechanism, directly linking the enterprise's digitalization level, emission reduction effect, ESG compliance status, cooperation qualifications, and order allocation, using institutionalized incentives and constraints to cultivate a virtuous cycle industrial ecosystem [19].

4.4. Deepen the Integration of Organizational Mechanisms and Promote The Deep Binding of Technology and Systems

The deep integration of technology and systems cannot be achieved without the support of the internal organizational structure of the enterprise. The implementation effect of external policies and industry standards ultimately depends on the departmental collaboration and management coordination capabilities within the enterprise. Breaking through the rigid departmental barriers is the core key to solving the disconnection between technology, business, and systems, and is also the foundation for ensuring the regular implementation of digital empowerment effects.

Enterprises need to establish a regular cross-departmental collaboration mechanism, uniformly promote digital construction and green governance work, and promote the multi-departmental collaboration and office work of technology, production, compliance, etc., to eliminate the drawbacks

of independent operation and poor connection among departments. Enterprises should lay out the core goals of low-carbon transformation, compliance operation, and green development in advance, and fully integrate these core goals into the design, establishment, and iteration process of the digital platform, so that the digital system can be adapted to the practical needs of green governance from the very beginning. Core governance indicators such as energy consumption control, carbon accounting, and green supervision should be embedded in the system modules, truly achieving intelligent and refined governance throughout the process [20].

Enterprises need to completely abandon the loose management model of post-event rectification and promote the upgrading of green governance to a regular, pre-positioned, and refined direction. After breaking through the connection barriers between technology application and system management, digital technology can continuously provide technical support for green governance, and standardized systems can effectively restrain digital application scenarios. The two cooperating and complementing each other can maximize the release of governance value and ensure the steady progress and long-term implementation of sustainable development work in the supply chain.

5. CONCLUSION

Digital transformation and the upgrading of supply chain governance are two core levers that support the high-quality and sustainable development of the manufacturing industry. Digital technologies can effectively solve practical problems such as lagging supervision in traditional supply chains, data distortion, and decentralized governance, providing stable technical support for refined and green governance; a complete governance system can standardize digital application scenarios, avoid transformation chaos, and ensure the orderly progress of digitalization. The closed-loop governance system formed by the synergy of these two aspects can continuously promote the green and low-carbon upgrading of the industrial chain.

Based on the actual operations in the industry, there are four main issues that restrict the of digitalization and governance systems： large differences in enterprise digitalization levels, inconsistent industry data standards, imbalance in the distribution of industrial chain interests, and insufficient integration of technology and system. These various problems interweave and jointly hinder the green transformation of the manufacturing industry's supply chain. This paper builds a systematic optimization plan from four perspectives： hierarchical transformation, standard construction, mechanism optimization, and organizational integration. The proposed countermeasures are highly practical and feasible, and can provide effective references for the long-term green governance and industrial upgrading of the manufacturing industry's supply chain.

This research has certain limitations. This paper mainly adopts qualitative analysis and industry experience summaries, focusing on the coordination mechanism, current predicaments, and optimization paths. No quantitative models are introduced for empirical analysis； at the same time, the research focuses on the overall manufacturing industry and does not conduct differentiated research on specific fields and enterprises of different scales. The applicability of the conclusions is limited. Future research can introduce panel data for quantitative analysis, accurately calculate the impact mechanism and effect of the coordinated development, and refine and optimize the plan based on the characteristics of specific industries, further improving the research system for the green and sustainable development of the manufacturing industry's supply chain.

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