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# Research on Metaverse Virtual Exhibition and Sales and Remote Inspection of Biopharmaceutical Equipment

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## Abstract:

Through digital transformation and the application of information technologies, the pharmaceutical equipment manufacturing industry is encouraging pharmaceutical enterprises to experiment with remote inspection technologies in equipment acceptance. Because of their complexity and the requirements of a strictly aseptic production environment, precision pharmaceutical machinery encounters considerable difficulties under the traditional on-site acceptance approach: high transportation costs, the inability to test all functions, and unclear allocation of responsibility occur from time to time. As a new approach, remote acceptance can substantially reduce delivery time and improve the efficiency of cooperation across the entire industry chain. At present, however, most enterprises have carried out only simple informatization upgrades in the form of video conferencing or photographs, which cannot meet the requirements of the Good Manufacturing Practice for Pharmaceutical Products (GMP) regarding equipment qualification. Starting from the characteristics of remote monitoring and drawing on the relevant content of service supply chain management, this paper analyzes and studies its development process and related issues. It is hoped that the study will provide some reference value for establishing a lawful, compliant, efficient, and traceable testing service for medical equipment.

## Keywords:

Metaverse, Industrial Equipment, Virtualized Presentation, Remote Inspection, Service Supply Chain

## 1. Introduction

Since 2021, the metaverse has evolved from a mere concept into a direction open to practical exploration, resting on a cluster of key technologies including virtual reality (VR), augmented reality (AR), digital twins, and three-dimensional modeling. In the field of e-commerce, some scholars contend that immersive interaction can stimulate consumers' purchase intention; Pillai et al. conducted related empirical research and proposed the mechanisms through which technology fit, sensory experience, and personalization shape consumer purchase behavior [1]. Wu Songqiang et al. constructed a metaverse value-creation framework along three dimensions (key elements, creation process, and creation context) and defined customer participation in virtual scenarios as the "value encounter" stage [2]. Most existing studies

concentrate on consumer goods, and applications in the B2C domain are already relatively mature; Yang You et al. also systematically reviewed interactive media technologies in the metaverse, such as light-field acquisition, multi-view video coding, and three-dimensional display [3]. By contrast, how industrial products, particularly heavy industrial equipment, can leverage the metaverse to advance e-commerce remains at an early stage and calls for further research and refinement.

In the process of bringing industrial equipment onto e-commerce platforms, the greatest obstacle is not low transaction-matching efficiency but the absence of user experience. Unlike ordinary goods, which can be judged from photographs, textual descriptions, and customer reviews, the purchase of precision pharmaceutical equipment involves process-compatibility assessment, compliance certification, and contract negotiation, tasks that all require the participation of domain professionals. Traditional offline approaches build customer trust through site visits, technical communication, and product inspection. Online platforms can save part of the cost, yet they cannot establish a depth of trust comparable to that achieved offline. According to the Statistical Bulletin on the Telecommunications Industry issued by the Ministry of Industry and Information Technology and to relevant industry white papers, the transaction scale of China's industrial products e-commerce continues to expand, but the online fulfillment and acceptance stages for heavy-decision categories lag markedly behind [4,5].

In the biopharmaceutical domain, downstream purification equipment mainly consists of chromatography systems, ultrafiltration modules, and online liquid-preparation systems. During development and production, such equipment must satisfy pressure-vessel requirements and possess well-developed automated control systems together with comprehensive quality assurance systems compliant with GMP standards. Its evaluation criteria are therefore no longer confined to technical specifications or hardware configuration; more important is whether the design of the production process is sound and feasible and whether the final performance can reliably and consistently guarantee product quality. The TCM Industry 4.0 strategy proposed by Cheng Yiyu et al. outlined, at an early stage, a technology roadmap for the transition from digital to intelligent pharmaceutical manufacturing, but its focus remained on process control and online inspection at the production end and did not extend to transaction and delivery [6]. Likewise, the review by Jiang Hong et al. of progress in AI-enabled biomanufacturing also concentrates on R&D and production efficiency and does not touch upon business delivery scenarios [7].

Although some studies have mentioned the connection between the two, few have offered a systematic discussion from this perspective. In particular, for industrial equipment B2B e-commerce platforms, there is still insufficient discussion on how to use metaverse technologies such as Virtual Reality (VR) or Augmented Reality (AR) to build professional trust between buyers and sellers. This paper focuses on the two aspects of presentation and inspection, seeking to address these issues and to explain their underlying causes (see Figure 2). Compared with prior work, this paper makes the following breakthroughs: first, it is the first to combine virtualized presentation with remote inspection and apply them to industrial equipment B2B e-commerce, offering a new approach to the application of metaverse technology; second, it elaborates in detail the benefits that metaverse technology brings to industrial equipment B2B e-commerce and the impact it exerts on traditional business models. From the perspective of supply chain management, this paper proposes a three-tier capability model comprising a visualization module, a cognition processing module,

and a trust-building module, which offers strong guidance for the design of multi-dimensional functional integration and facilitates its application and testing in practice. Taking precision pharmaceutical equipment as a case, it discusses in detail how each capability tier operates, the remote inspection interaction modes involved, and the problems that may arise in its wider adoption.

## 2. Theoretical Framework: A Capability System Integrating Presentation and Inspection

### *2.1. Incorporating the Service Supply Chain Perspective*

Traditional supply chains focus primarily on the physical transportation of products. In industrial equipment e-commerce, however, it is necessary to establish a service system capable of delivering both product delivery and professional technical service. The concept of the service supply chain proposed by Ellram et al. holds that this is a process of systematic coordination and cooperation encompassing information flow, logistics, value networks, service quality, and capital flow [8]. From an application standpoint, this implies two things: on the one hand, the most difficult problem in service delivery is not how to design an excellent user experience but how to integrate all available resources to achieve the best outcome; on the other hand, effective capability integration is crucial to improving service capability, and no single technology or method can by itself resolve all problems. This paper defines industrial equipment e-commerce service delivery as a process characterized by professional technical content and trust building, in which presentation effectively mitigates information asymmetry between buyers and sellers, while inspection substantially reduces quality uncertainty in transactions, thereby enabling both parties to gradually build mutual trust. This judgment echoes the metaverse value co-creation logic described by Wu Songqiang et al.: customers are not passive price takers but participate in value creation through continuous contact spanning presentation, inspection, and subsequent services [2].

### *2.2. The Three-Tier Structure of Customer Needs and Corresponding Capability Requirements*

Given the particularities of precision pharmaceutical equipment procurement, and drawing on the Kano model's classification of need levels [9], customer expectations on e-commerce platforms are divided into three progressive tiers. The first is visibility, meaning perceivable: product information must be fully presented so that purchase objectives can be achieved. The second is comprehensibility, meaning easy to interpret: standards, detailed specifications, and technical parameters are required so that customers can clearly understand the function of the product. The third is trustworthiness, meaning reliable: this involves establishing sound after-sales service and strengthening quality certification to enhance customer confidence. When basic needs are not satisfied, higher-level emotional needs cannot become a driver of purchase.

### *2.3. Constructing the Three-Tier Capability System*

Building on the analysis of needs and a comprehensive study of capability models, a hierarchical and staged capability framework is established (see Figure 1). It consists mainly of three components: visual representation, knowledge interpretation, and trust evaluation. The framework unfolds from the bottom up in accordance with

the user's cognitive process. At the bottom lies the visualization component, which converts large volumes of complex data into simple, easily understandable forms for users to view. Next is the knowledge interpretation component, which is dedicated to uncovering the deeper meaning hidden behind this data and providing professional explanations. Finally, the trust evaluation component uses multiple channels to provide comprehensive quality assurance for the entire service or product. The objective of this clearly layered capability framework is to make the service system more complete and to provide users with a better experience.

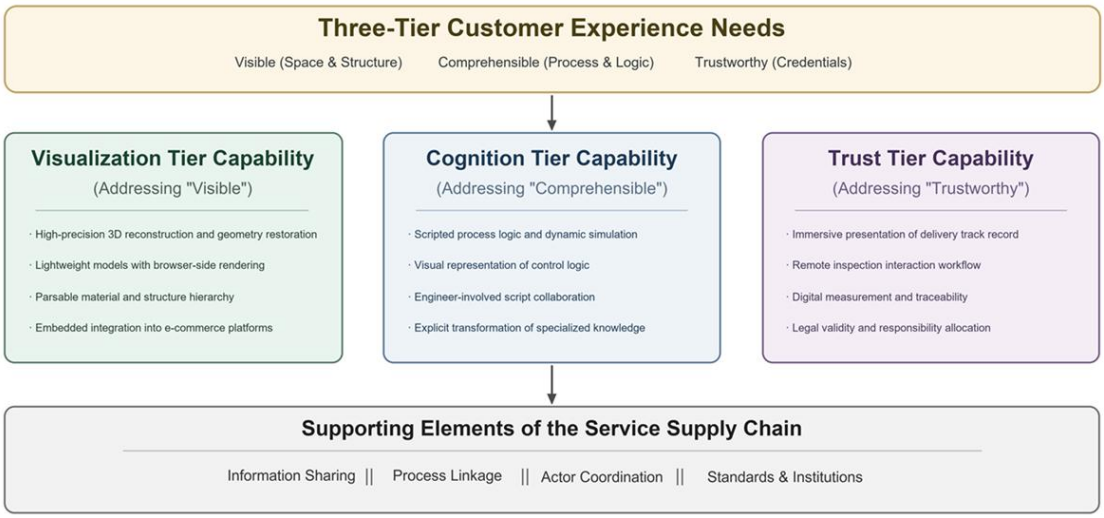


***Figure 1.*** *Three-tier capability framework for integrated presentation and inspection.*

## 3. Implementation Paths and Methods of Virtualized Presentation

On the basis of the capability model described above, this paper selects the chromatography system among precision pharmaceutical machinery for detailed analysis, and proposes a hierarchical, step-by-step virtualization scheme, describing the core capabilities, implementation methods, and prerequisites of each tier.

### *3.1. Visualization Tier: Three-Dimensional Reconstruction and Lightweight Rendering*

The visualization module is mainly responsible for faithfully presenting the three-dimensional geometry of the target equipment to users, achieving a what-you-see-is-what-you-get effect. It comprises three parts of work. The first is data acquisition: a three-dimensional laser scanner is used to obtain point cloud data of the target object, which are then accurately aligned with CAD drawings, recording the deviations arising during manufacturing as well as the overall appearance characteristics of the equipment. This step is consistent with the acquisition-processing-display three-dimensional visual data chain summarized by Yang You et al., and the quality of point cloud acquisition directly determines the fidelity of subsequent geometric reconstruction [3]. The second part is modeling: on this basis, hierarchical models at different levels are built according to the relationships among components. This allows users to observe the equipment from the whole down to individual parts, and also enables detailed material mapping of important locations such as stainless-steel surface textures and weld seams. The third part is display: the relationship between model complexity and network loading time must be considered. The LOD (Level of Detail) method is used to simplify models, and techniques such as normal mapping

are applied to greatly reduce data volume, so that the model can be viewed smoothly and quickly on a web page with a good user experience.

This tier mainly adopts an integrated scanning-modeling-optimization working mode. Lightweighting is not simply a reduction in model size; rather, it is a refined design approach based on user habits. On the basis of analyzing the visible parts of the target object (outline contours, interface structures, main components, and so on), different precision requirements are applied and combined with expert experience to complete the design, thereby achieving an optimal match between technology and professional knowledge. This reflects the sound integration of technical means and technical expertise. In terms of engineering implementation, Yin Yanchao et al. have validated a scheme for data acquisition and real-time virtual workshop driving based on the unified OPC UA architecture on a tobacco primary-processing pilot line in a process manufacturing enterprise, achieving full-process three-dimensional visual monitoring of a multi-stage production line [10]. This indicates that the transition from static models to data-driven models already has a foundation for implementation in China's process manufacturing scenarios.

### *3.2. Cognition Tier: Explicit Representation of Process Logic*

Its specific approach can be explained from three aspects. First, dynamic vector arrows are used to indicate the flow of feed liquid and buffer solution inside the pipelines, so as to give a better understanding of the material conveying process. Second, timeline-based animation is used to display the action sequence of each component in the main production process and the interactions among them, thereby providing an intuitive demonstration of the working principle of the control system. Third, PLC program logic is rendered graphically and integrated into the equipment model, forming a closed loop from sensor signal acquisition to the final execution of the corresponding action, thus embodying the operating mechanism of the entire automated control system. All three approaches aim to give users a clearer understanding of fluid properties, operating sequences, and control concepts. The focus of this tier is not technological innovation but knowledge transfer. Process logic depends on the experience of engineers and technicians and on project documentation; the key lies in the scriptwriting process carried out by process engineers, which converts tacit knowledge into explicit form, for example animation scripts. This is not only a process of content innovation but also a process through which enterprises build their own process knowledge base, a competitive advantage that is difficult to imitate. Similar demands exist in visualization monitoring research, where the key is to transform equipment status and process flows into a parseable unified object model [10].

### *3.3. Trust Tier: Immersive Presentation of Delivery Track Record*

The core function of the trust mechanism is to build a solid verification system that satisfies all parties' demand for reliability. In industrial equipment, past performance is often more persuasive than technical specifications and does more to inspire customer confidence. This process can use panoramic cameras to fully record the actual operation of equipment in a GMP workshop, and then allow customers, through VR or the web, to experience an already-delivered project site immersively and to view current data changes. This of course also involves customer privacy and permission issues, and because it is ultimately a cross-domain technology integration process involving multiple parties, certain difficulties remain in practical operation.

### *3.4. Comparison of Technical Routes across the Three Tiers*

Table 1 compares the implementation paths of the three-tier presentation scheme from four aspects: capability positioning, implementation path, technical tool, and service capability.

***Table 1.*** *Technical paths of the three-tier virtualized presentation scheme.*

| Capability Tier | Positioning | Implementation Path | Technical Tool |
|---|---|---|---|
| Visualization Tier | Lossless transmission of geometric and material information | Fused 3D laser scanning and CAD modeling;<br>Hierarchical modeling by structural level;<br>LOD simplification and normal map baking | Laser scanner<br>SolidWorks / Blender<br>WebGL |
| Cognition Tier | Explicit transformation of process knowledge | Script-based design of process logic;<br>Dynamic simulation of fluid paths and action sequences;<br>PLC logic represented as a process flow overlay | PLC program parsing<br>Unity / After Effects<br>WebGL interaction |
| Trust Tier | Verifiability of delivery track record and quality evidence | Panoramic recording of actual operating conditions;<br>Virtual roaming overlaid with operational records;<br>Digital traceability of remote inspection | 360° panoramic camera<br>WebVR / A-Frame<br>AR glasses and smart measuring instruments |

## 4. Implementation Paths and Interaction Workflow of Remote Inspection

### *4.1. Limitations of the Traditional Inspection Process*

Traditional pharmaceutical equipment inspection generally consists of two major parts: Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT). During FAT, the customer needs to assign technical personnel to the supplier's factory to check whether the various functions of the equipment meet requirements. This approach also has problems. First, it is constrained by time and space, and customers cannot arrange their schedules flexibly. Second, because a complete document management system has not been established, problems tend to be scattered and difficult to locate. Feasible paths already exist at the engineering level: Duan Jiujun, taking elevator inspection as the object, proposed a design approach encompassing an AR inspection system scheme, virtual-real registration, and display technology [11], indicating that there is no fundamental technical obstacle to the AR retrofitting of inspection procedures that rely mainly on visual examination.

### *4.2. A Four-Step Workflow for AR-Based Remote Inspection*

To overcome the shortcomings of previous research methods, this paper uses augmented reality (AR) technology to study remote inspection interaction and builds a remote inspection interaction platform, which consists of four parts: device-side deployment, user-side control, data acquisition and processing, and result presentation (see Figure 2). Its design concept is to use virtual reality technology to extend the user's field of view, so as to reduce the gap between remote control and the actual environment, and to improve interactivity and precision in remote inspection.

In the preparation stage before equipment delivery, the manufacturer needs to be equipped with augmented reality (AR) glasses; the problems to be solved in this process are ensuring viewpoint stability and human-machine interaction efficiency. The key here lies in the stability of spatial registration rather than merely transmission bandwidth. Xu Jinli et al. completed immersive virtual review in HoloLens after converting Matlab finite element analysis results through VTK and dae formats, confirming that a complete closed loop from numerical computation to mixed reality review can be realized [12].

On the client interaction side, customers use professional software on a PC or tablet to acquire and parse video data streams. After submitting inspection requests by voice or on-screen annotation, the relevant information is displayed to the engineer's operation interface in the form of augmented reality and accurately mapped onto the corresponding area. This not only converts the customer's subjective perception into an actionable guide, but also overcomes what traditional single-channel video monitoring cannot achieve, demonstrating the advantages of remote quality inspection.

This digital inspection unit uses modern intelligent measuring instruments such as Bluetooth range finders and electronic surface roughness testers to perform inspection, then uploads the acquired information in real time and compares it with the preset standards; data that fall outside the range are marked with conspicuous flags, and each data item is stamped with a time stamp and the name of the operator. This greatly reduces errors caused by manual reading and transcription and improves data accuracy and traceability.

After the inspection is completed, the system automatically generates a unified-format inspection report and uses electronic signatures so that all participants reach agreement on the report content. The report satisfies the GMP requirements regarding traceability, and can link scattered inspection materials into a complete evidence chain, which is then stored securely and preserved over the long term.

### *4.3. Full-Process Integration and Key Risk Points*

Presentation and inspection are important components of the service system; they do not exist in isolation but are parts of an integrated service process. This service process contains several important nodes (see Figure 2): needs investigation, solution negotiation, virtual presentation, remote inspection, evaluation and feedback, and after-sales service are all indispensable. They are interconnected and mutually influencing, constituting a complete process of information flow and functional interaction.

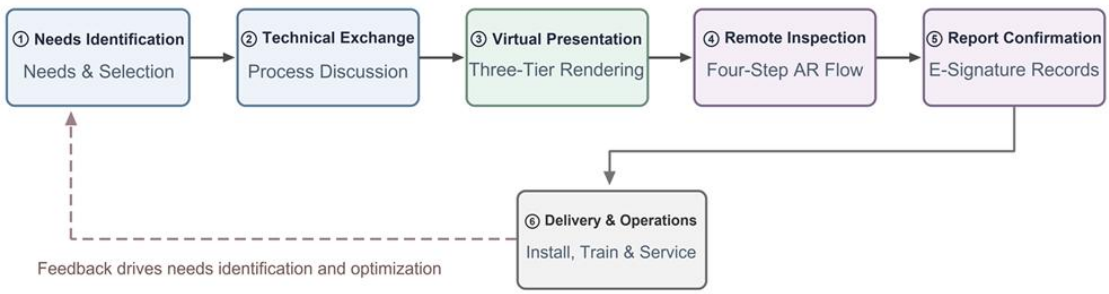


***Figure 2.*** *Integrated workflow.*

In the process integration stage, four major risks are identified and summarized (see Figure 3). First, the problem of missing trust: some consumers have reservations

about online presentation, and the habit of traditional offline inspection cannot be changed in the short term. Second, the absence of corresponding regulations and measures: enterprises lack internal provisions on remote inspection, and relevant laws and regulations are still at an early stage. Third, unclear responsibilities: the division of roles between executors and managers is not clear, which hinders the investigation and resolution of problems. Fourth, insufficient technical support: a shortage of technical personnel and incomplete cross-departmental collaboration mechanisms affect the progress of the entire project. These risks correspond to several elements in the capability model, and resolving them requires simultaneous action on both optimizing business process design and improving institutional development.

***Figure 3.*** *Key risk points.*

### *4.4. Analysis of Legal Validity*

The legal validity of remote inspection reports is a fundamental prerequisite for their widespread application. The Electronic Signature Law of the People's Republic of China (as amended in 2019) expressly stipulates that, under certain conditions, data messages in electronic form may have the same legal effect as paper documents [13]. To avoid or minimize the various problems arising therefrom, relevant provisions can be improved in the following respects: first, the entire remote inspection process should be audio- and video-recorded throughout, and cryptographic methods should be used to ensure secure data storage; second, the main inspection content should be fixed and stored in a tamper-proof manner; third, contracts should clearly state the differences between remote inspection and traditional on-site inspection as well as their respective applicable circumstances; fourth, when necessary, an intermediate agency may be engaged to serve as witness or supervisor.

## 5. Conclusions and Future Research

From the perspective of service supply chain management, this paper explores the service innovation that combines virtual exhibition and sales with remote inspection in the industrial equipment sector. The study argues that in the process of bringing industrial equipment onto e-commerce platforms, establishing professional domain trust is a key issue, and presentation and inspection are part of it. The analysis of customer experience needs shows that visibility, comprehensibility, and trustworthiness constitute a progressively ascending hierarchy of needs. Accordingly, this paper proposes a three-tier capability enhancement approach consisting of a perception tier, a cognition tier, and a trust tier, and gives concrete measures: at the perception tier, three-dimensional scanning and CAD model integration are used to make equipment information easier to see; at the cognition tier, standardized design of the production process is used; at the trust tier, digital evidence preservation and the deployment of remote monitoring are used to increase both parties' confidence in the results.

This study also has limitations. In terms of research method, the present work has only completed the formulation of research ideas and schemes and has not yet entered

the stage of actual data collection. From the perspective of technical feasibility and economic efficiency, this paper mainly relies on publicly available materials and prior project experience for its analysis. Therefore, the specific scope within which the proposed recommendations can be executed in practice still needs to be further determined.

As digital technologies continue to develop and manufacturing transitions toward intelligent manufacturing, the virtual presentation and remote monitoring of industrial equipment have already achieved high-precision visualization, multiple interaction modes, and a relatively high level of security. Against this background, research on this topic can proceed from two directions. On the one hand, a complete evaluation standard can be designed, using real user experience to measure system usability, comprehensibility, and reliability, and applying statistical methods to test whether the results are sound. On the other hand, generative artificial intelligence (AIGC) technology can be fully utilized to make progress in production process modeling, virtual environment construction, and fault simulation training, thereby greatly improving work efficiency and innovation capability. The adoption of e-commerce for industrial equipment is not only a commercial issue but also a direction for the servitization of manufacturing, and it requires continuous research and experimentation by both academia and industry.

## Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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