

# Application of Standardized Agricultural Implement Interface Design in Multi-Implement Combined Operations

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**Abstract:** The development of precision agriculture and smart agriculture has imposed higher requirements on agricultural production, making multi-implement combined operations an inevitable trend. However, the current agricultural implement market is highly fragmented, and the lack of universality and interoperability among different implements severely constrains the flexibility and efficiency of collaborative operations. Focusing on standardized interface design for agricultural implements, this paper first analyzes the technical connotations, current status, and challenges of multi-implement combined operations, identifying interface incompatibility as the primary bottleneck. It then systematically examines the overall architecture of standardized interfaces, elaborating on the design principles, key technologies, and standard specifications of sub-interfaces from four dimensions: mechanical, hydraulic, electrical, and information communication. On this basis, a collaborative operation model based on standardized interfaces is constructed. Finally, future development trends toward intelligence, modularization, and platformization are discussed, and corresponding policy recommendations and technical pathways are proposed. The results indicate that establishing and promoting a scientific and unified interface system is critical to enabling multi-implement collaborative operations and is of great significance for the mechanized and intelligent transformation of agriculture.

**Keywords:** Agricultural implements; standardized interfaces; multi-implement combination; collaborative operation; smart agriculture; interoperability

## Introduction

In the 21st century, global agriculture has entered a phase of digital and intelligent transformation, with emerging technologies such as the Internet of Things being deeply integrated into the entire agricultural production process. Traditional single-implement operation modes can no longer meet the

comprehensive demands of modern agriculture for high efficiency, high quality, low cost, and sustainability. Consequently, multi-implement combined operations have emerged. By rapidly coupling and collaboratively controlling multiple functional implements, this approach enables “one field pass, multiple operations,” thereby improving land and energy utilization



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efficiency as well as overall operational performance. At present, however, the global agricultural machinery industry ecosystem remains severely fragmented. Implements produced by different manufacturers adopt disparate approaches in physical connections, hydraulic circuits, and other aspects, resulting in “information silos” and “hardware barriers.” As a result, farmers often face high adaptation costs, complex retrofitting requirements, or even incompatibility when replacing or adding implements. This not only restricts users’ freedom of choice but also makes the vision of multi-implement combined operations difficult to realize. Therefore, the design of standardized interfaces for agricultural implements is of critical importance. By defining a unified “language” and “actions” for agricultural equipment, standardized interfaces can enable plug-and-play functionality and serve as a key solution to industry pain points, as well as a foundation for building future agricultural equipment ecosystems. Conducting systematic research in this area is thus of great practical and strategic significance.

## **1. Connotation, Current Status, and Challenges of Multi-Implement Combined Operations**

### **1.1 Technical Connotation**

Multi-implement combined operations constitute a highly integrated systems engineering approach, with collaboration as the core concept, manifested in three key aspects. First is physical collaboration, whereby multiple implements can be stably and safely mounted and operated on the same power platform, with non-interfering spatial layouts and shared operational loads. Second is energy collaboration, in which the power platform (typically a tractor) supplies stable and controllable power to mounted implements through standardized energy interfaces (hydraulic and electrical), meeting their respective power requirements. Third is information collaboration, where implements exchange data bidirectionally, in real time, and reliably with the tractor central control unit (TCU) via a unified data bus. Based on preset agronomic prescription maps or real-time data, the TCU precisely coordinates and controls each implement to ensure consistent and accurate operational parameters. Such collaborative capability enables operational efficiency and precision far exceeding those of traditional single-

implement operations<sup>[1]</sup>.

### **1.2 Development Status**

In some developed countries, multi-implement combined operations have already seen preliminary application. In the Great Plains region of North America, farmers commonly use integrated spring sowing equipment that combines strip tillage, fertilization, and seeding. In Europe, composite tillage implements integrating deep loosening, rotary tillage, ridging, and mulching are relatively common. However, most of these combinations are fixed or semi-fixed in nature and essentially represent “large integrated implements,” rather than truly modular systems that users can freely configure. In China, multi-implement combined operations are still at the stage of pilot demonstration and exploration. Some large state-owned farms and agricultural cooperatives have attempted to introduce or independently develop simple combined implements. Nevertheless, due to interface incompatibility, complex control systems, and other constraints, large-scale promotion remains limited, and the expected economic benefits have not yet been fully realized.

### **1.3 Major Challenges**

The first challenge is severe interface heterogeneity. Significant differences exist among implements from different manufacturers in terms of mechanical hitch dimensions and hydraulic quick-coupler specifications, making cross-brand and cross-model collaboration impossible. This is the most fundamental obstacle. The second challenge is closed control systems. Many high-end agricultural implements adopt proprietary electronic control unit (ECU) algorithms and communication protocols, forming technical barriers that prevent data sharing and the acceptance of external control commands. The third challenge is the lack of unified standards. Although international and national standards exist, their coverage is incomplete, updates are slow, and supporting regulatory and certification mechanisms are insufficient, making effective implementation difficult. The fourth challenge relates to user awareness and cost concerns. Small and medium-sized farmers often lack a clear understanding of the advantages of combined operations and worry that standardized retrofitting or purchasing new equipment will increase financial burdens. Among these

challenges, interface heterogeneity is the root cause. Addressing it requires a top-level design approach to establish a comprehensive standardized interface system for agricultural implements.

## 2. Architecture of the Standardized Interface System for Agricultural Implements

A complete standardized interface system for agricultural implements should adopt a multidimensional and hierarchical architecture, covering the entire process from physical connection to information interaction. In this study, the system is divided into four core sub-interfaces: mechanical interfaces, hydraulic interfaces, electrical interfaces, and information communication interfaces.

### 2.1 Standardization of Mechanical Interfaces

#### 2.1.1 Design Principles

First, universality: the interface structure should be capable of meeting the coupling requirements of the vast majority of mainstream tractors and implements. Second, interchangeability: any implement conforming to the standard should be able to achieve seamless physical connection with any tractor that also meets the standard, without differentiation<sup>[2]</sup>. Third, safety: the interface must incorporate reliable locking and anti-detachment mechanisms to ensure secure connections under severe vibration or high-load operating conditions. Fourth, convenience: the interface should support rapid coupling and decoupling, preferably enabling single-operator handling.

#### 2.1.2 Key Technologies and Standards

(1) Primary hitch interface: optimization and extension should be based on the existing three-point hitch system (ISO 730). For implements requiring greater load-bearing capacity or more complex motion, four-point or five-point hitch concepts may be introduced, with more refined specifications for the dimensions, tolerances, and material strength of lower links, lift arms, and top links.

(2) Auxiliary positioning and guiding mechanisms: by adding standardized lateral limiting pins and automatic self-centering guide cones to the three-point hitch system, operator convenience can be significantly enhanced and coupling time substantially reduced.

(3) PTO (Power Take-Off) interface: as the key component for transmitting rotational power, PTO

interfaces should strictly implement the ISO 500 or ISO 501 series standards, unifying shaft diameters, spline specifications, and rotational speeds (540/1000 rpm), while also mandating standardized designs for safety guards.

### 2.2 Standardization of Hydraulic Interfaces

#### 2.2.1 Design Principles

First, pressure and flow compatibility: standardized working pressure levels (e.g., 200 bar, 250 bar) and flow rate ranges should be defined to ensure proper matching between implements and tractor hydraulic pumps. Second, independent and controllable circuits: each implement function (such as lifting, tilting, opening, and closing) should correspond to an independent hydraulic circuit to facilitate precise control. Third, error-proofing and leak prevention: interface designs should incorporate foolproof (keyed) features to prevent incorrect connections, while high-quality quick couplers should be used to ensure reliable, leak-free operation.

#### 2.2.2 Key Technologies and Standards

(1) Quick couplers: the widespread adoption of ISO 16028 (flat-face sealing type) or ISO 5675 (agricultural quick coupler) standards should be promoted. These couplers feature color coding, size coding, and misconnection-prevention designs.

(2) Hydraulic circuit topology: standard specifications should define the number of hydraulic circuits (e.g., at least four circuits: two for lifting/lowering and two for implement function control) and their standardized layout on the interface panel.

(3) Pilot control: for implements requiring fine flow regulation, standardized pilot control signal interfaces should be supported, allowing the TCU to regulate the opening of main valve spools via low-flow pilot oil.

### 2.3 Standardization of Electrical Interfaces

#### 2.3.1 Design Principles

First, unified power supply: standardized DC power sources (e.g., 12 V/24 V) should be provided, with clearly specified maximum current output capacities. Second, signal isolation: digital signals, analog signals, and power lines should be properly shielded and isolated to prevent mutual interference<sup>[3]</sup>. Third, clear pin definitions: the function of each pin (such as power, ground, CAN\_H, CAN\_L, PWM signals, etc.) must be

clearly and uniquely defined.

### 2.3.2 Key Technologies and Standards

(1) Physical connectors: robust, waterproof, dustproof, and vibration-resistant industrial-grade connectors should be adopted. The DEUTSCH DT/HD series or TE Connectivity CPC series connectors, due to their excellent performance, can serve as reference standards.

(2) Pin assignment: pins within the connector should be strictly allocated according to function. For example, pins 1–2 may be designated for power and ground, pins 3–4 for the CAN bus, and pins 5–8 reserved for PWM or digital I/O signals.

## 2.4 Standardization of Information Communication Interfaces

### 2.4.1 Design Principles

First, openness: communication protocols must be open and non-proprietary, allowing any manufacturer to access and implement them free of charge or at low cost. Second, real-time performance and reliability: low-latency and highly reliable transmission of control commands and status feedback must be ensured. Third, scalability: protocol design should accommodate future additions of new implement types and functions.

### 2.4.2 Key Technologies and Standards

(1) Core protocol: ISOBUS (ISO 11783) is currently the most mature and widely applied agricultural machinery communication standard and should serve as the cornerstone of China's agricultural implement information communication interface system. Based on the CAN 2.0B bus, it defines comprehensive functions such as network management, task controller (TC), virtual terminal (VT), and auxiliary control unit (AUX-N).

(2) Object Pool: through object pool technology, ISOBUS allows implement manufacturers to define their control interfaces graphically, which are then rendered by the tractor's VT. This fundamentally resolves the issue of different implements requiring different physical terminals<sup>[4]</sup>.

(3) Task data recording (TDR): standardized formats for operational data (e.g., ISO 11783-10) facilitate subsequent data analysis, traceability, and farm management.

(4) Future evolution: in view of future demands for

higher bandwidth (such as video streams and LiDAR data), forward-looking research should be conducted on the application potential of Ethernet-based technologies (e.g., SAE J1939 over Ethernet) or 5G-V2X in the agricultural machinery domain, along with the formulation of appropriate transition strategies.

## 3. A Multi-Implement Collaborative Operation Model Based on Standardized Interfaces

With the standardized interfaces described above as a foundation, an ideal multi-implement collaborative operation model can be constructed.

### 3.1 System Architecture

The proposed model adopts a “one-tractor–multiple-implements” star topology. The central node is an intelligent tractor equipped with a standardized interface panel, whose core component is the Tractor Central Unit (TCU). The TCU integrates multiple functions, including navigation, decision-making, communication, and energy management. Surrounding the TCU,  $N$  ( $N \geq 1$ ) intelligent agricultural implements with different functions can be connected via standardized mechanical, hydraulic, electrical, and information communication interfaces. Each implement is equipped with its own Implement Control Unit (ICU), which is responsible for executing commands issued by the TCU and collecting local operational status data to be transmitted back to the TCU.

### 3.2 Collaborative Operation Workflow

(1) Task planning: The farm owner or agronomist develops a detailed agronomic operation prescription map using Farm Management Software (FMS) in the office, specifying the required operation types for different fields (e.g., deep loosening + fertilization + precision seeding).

(2) Implement selection and configuration: Based on the prescription map, the user selects a deep loosening implement, a fertilizer applicator, and a precision seeder that all comply with the standardized interface specifications available on the market.

(3) Rapid coupling: In the field, the operator sequentially connects the three implements to the tractor using standardized three-point hitches, hydraulic quick couplers, electrical connectors, and ISOBUS communication cables. The entire coupling process can

be completed within a few minutes.

(4) System self-check and identification: After the tractor is started, the TCU automatically scans and identifies all connected implements via the ISOBUS network, reads their Task Controller Description (TC.DES) files, and automatically generates the corresponding control interfaces on the universal Virtual Terminal (VT) in the cab.

(5) Collaborative operation execution: The tractor operates in automatic driving mode along a predefined path. Based on GPS positioning, the TCU queries the prescription map in real time and transmits the corresponding control commands (such as deep loosening depth, fertilizer application rate, and plant spacing for seeding) to the three ICUs via ISOBUS. Each ICU executes the commands precisely and provides real-time feedback on operational status (e.g., actual fertilizer rate and blockage alarms) to the TCU. The TCU aggregates all information and generates a complete operation log.

(6) Operation completion and decoupling: Upon completion of the operation, the operator performs one-click decoupling of all implements, and the system automatically saves the operational data.

## Conclusion

This paper systematically demonstrates the decisive role of standardized agricultural implement interface design in promoting the development of multi-implement combined operations. It argues that establishing a unified, open, and standardized interface system encompassing four dimensions—mechanical, hydraulic, electrical, and information communication—is the fundamental approach to resolving market fragmentation and achieving cross-brand interoperability among agricultural implements. Such a system can significantly enhance agricultural production efficiency and intelligence, reshape

the industry ecosystem, and thus holds substantial strategic value. In the future, standardized interfaces will evolve toward intelligent, modular, and platform-based development. Interfaces will integrate more functions, implements will be freely combinable, and third-party developers will be attracted to create intelligent applications based on open platforms. To accelerate practical implementation, it is recommended to strengthen top-level design, with relevant national authorities taking the lead in formulating mandatory national standards; establish certification systems to guide market consumption; increase policy support by providing tax incentives and R&D subsidies to enterprises and preferential purchase subsidies to users; and promote international cooperation by actively participating in the formulation and revision of international standards, thereby enhancing the global competitiveness of China's agricultural equipment industry.

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