Multi-machine collaboration realization conditions and precise and efficient production mode of intelligent agricultural machinery

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Abstract: Multi-machine collaboration of agricultural machinery is one of the international frontier and hot research in the field of agricultural equipment. However, the current domestic multi-machine collaborative operation of agricultural machinery is limited to the research of task goal planning and collaborative path optimization in a single production link. In order to achieve the purpose of zero inventory of agricultural materials and precise and efficient production operations, a new technology of agricultural machinery multi-machine collaboration with multi-dimension and full chain was proposed, which takes into account the whole process of agricultural production, as well as agricultural machinery system and external supply chain, storage and transportation chain collaboration. The problems of data collaboration, process collaboration and organization collaboration were analyzed. And the realization conditions of new multi-machine cooperative technology were analyzed. Meanwhile, the zero inventory mode and precise operation mode of agricultural materials under the background of multi-machine cooperation of intelligent agricultural machinery were studied. Then, a precise and efficient agricultural production mode based on data-process-organization collaboration was constructed. The results showed that the multi-machine cooperative technology mode of multi-dimensional and full-chain agricultural machinery could greatly improve the efficiency of agricultural machinery, operation quality, land utilization rate and reduce production cost.

Keywords: intelligent agricultural machinery, multi-machine collaboration, multi-dimensional, whole chain, zero inventory, precise and efficient, production mode

DOI: 10.25165/j.ijabe.20241702.8127

Citation: Wang B, Du X X, Wang Y N, Mao H P. Multi-machine collaboration realization conditions and precise and efficient production mode of intelligent agricultural machinery. Int J Agric & Biol Eng, 2024; 17(2): 27–36.

1 Introduction

There are two different development directions of modern agricultural machinery[1,2]. One is to develop in the direction of super large scale and complexity. The other is to improve production efficiency through the collaborative operation of multiple small agricultural machinery[3]. Multi-machine cooperative control of agricultural equipment is divided into master-slave cooperative control and common operation control. In the large-scale farmland environment, different tractors and agricultural machinery have realized the automatic optimal allocation operation, which effectively guarantees the connection between the operation lines and improves the efficiency of agricultural machinery and land utilization[4,5]. In addition, in the farmland operating environment with large quantity and small area, the multi-machine cooperative working system will carry out reasonable task planning according to the performance parameters of each farm machine and the location and geometric parameters of each farm, so as to ensure the minimum operation cost of the farm machine group and effectively shorten the operation time, which is of great significance for the harvesting of seeds and crops with strict operation window period requirements[6]. It is one of the international frontier and hot research issues in the field of agricultural equipment[7-9].

Nowadays, domestic and foreign scholars have carried out a series of research on multi-machine coordination and efficient production technology of agricultural machinery[8-12].

Burgard et al.[13] proposed a sliding mode control method for the master-slave co-operating tractor, which can be used to asymptotically stabilize the following vehicle to the desired path and realize the stable distance and deflection Angle between the slave and the main engine. Shojad et al.[14] designed an adaptive neural network leading tracking control for multiple tractors based on saturation observer. The constrained error dynamics were transformed into a new second-order Euleran-Lagrangian unconstrained error dynamics model by using coordinate transformation and non-online error transformation, which realized cooperative control of multiple tractors. Zhang et al.[15] proposed a control method for two cooperative tractors in leader-following mode to avoid collision in the head turn, which ensured the non-collision steering of tractors on the premise of making full use of the head turn area. Noguchi et al.[16] used integral sliding mode control to realize distance control and lateral control between slave and main engine of automatic guided tractor.

However, the multi-machine collaborative operation of

Received date: 2023-01-01 **Accepted date:** 2023-12-10

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domestic agricultural machinery is mostly limited to the research of task goal planning and collaborative path optimization in a single production link. There is no comprehensive consideration of agricultural machinery collaboration in the whole process of agricultural production, the collaboration between agricultural machinery system and external supply chain, storage and transportation chain, and the multi-machine collaboration of agricultural machinery with comprehensive planning of agricultural machinery equipment, accessories, agricultural materials and other resource inventory. Therefore, in order to achieve zero inventory of agricultural materials and precise and efficient production operations, a multi-machine collaborative technology of multi-dimensional and full-chain agricultural machinery was proposed in this study. Meanwhile, the realization conditions of multi-dimensional and full-chain agricultural machinery multi-machine collaborative technology, agricultural zero inventory mode and precise and efficient production mode are studied.

2 Multi-machine collaboration technology of multi-dimensional and whole chain agricultural machinery

The multi-machine collaborative operation architecture of agricultural machinery mainly includes server side and agricultural machinery automatic driving end, which jointly complete the dynamic task allocation of multi-machine collaborative operation of agricultural machinery. The server side can realize the storage of high-precision maps of fields, agricultural machinery operation width and operation performance, field location and other information. The server side not only has the task allocation algorithm, which can allocate tasks according to the task information and the agricultural machinery information that needs to be executed, but also has the communication function with the terminal controller. Meanwhile, it also has the function of data loading and saving, and can update the operation performance information of agricultural machinery according to the loaded operation information. Furthermore, it also has the function of path planning, which can plan the operation path of agricultural machinery according to different parameters of agricultural machinery and land parameters. The automatic navigation terminal of agricultural machinery has wireless communication, data processing, path tracking, obstacle avoidance, multi-machine collaboration, dynamic task allocation and other modules.

Specially, the agricultural machinery terminal communicates with the server through 4G or 5G. The agricultural machinery terminal mainly uploads the real-time location information and operation information of the agricultural machinery, and downloads the task information, path planning information and dynamic task allocation information issued by the server. The agricultural machinery path tracking module performs field path tracking according to the path issued by the server or according to the path planned by itself. The multi-machine collaborative module enables agricultural machinery to work in parallel with a certain lateral distance, or to perform master-slave follow-up collaborative operations with a constant linear distance and angle deviation (Figure 1)[17], collaborative operations of unmanned combine harvester and grain truck (Figure 2). The dynamic task allocation module mainly implements the dynamic task assignment function when agricultural machinery encounters in the process of executing tasks. The agricultural machinery control terminal controls each execution part of the agricultural machinery.

Multi-machine collaboration is a new technology in the field of intelligent control of agricultural machinery. At present, it mainly focuses on the research of leader-follower collaborative algorithm[18,19]. In the future, collaborative technology will be practical. In addition to the leader-follower algorithm, it is necessary to solve the problems of single machine anomaly diagnosis and formation recovery, cross-regional air-ground collaboration, cloud collaborative scheduling, agricultural equipment cluster collaborative operation management and control platform technology, multi-agricultural equipment cluster collaborative cloud scheduling technology, distributed multi-machine collaborative remote operation and maintenance technology, man-machine accompanying control technology and so on[3].

Figure 1 Master-slave tracking operation of tractor unit

Figure 2 Cooperative operation of unmanned combine harvester and grain truck

Nowadays, the research on multi-machine collaborative operation of agricultural machinery in China is mostly limited to the research on task goal planning and collaborative path optimization of single production link. There is no collaborative research on agricultural machinery multi-machinery that comprehensively considers the collaboration among the agricultural machinery system and the external supply chain and the acquisition/storage chain in the agricultural production process, as well as the comprehensive planning of resources inventory such as agricultural machinery equipment, accessories and agricultural materials. Therefore, a multi-dimensional and full-chain intelligent agricultural machinery multi-machine collaboration technology (intelligent agricultural machinery multi-machine collaboration technology) is proposed, which includes three aspects. One is the collaboration within the intelligent agricultural machinery, that is, the autonomous collaboration within the agricultural machinery system, between agricultural machinery and multi-machine collaboration operation. The second is the collaboration of all links of intelligent agricultural machinery. The configuration of intelligent agricultural machinery in farming, planting, managing

and harvesting production links and the seamless link of all links of agricultural machinery. The third is the collaboration between the intelligent agricultural machinery system and the external (means of production, accessories, etc.), the collaboration between the multi-link intelligent agricultural machinery configuration in the whole process of agricultural production and the upstream and downstream supply, purchasing and storage chain, that is, the collaboration of agricultural machinery cluster, various production environment operations, agricultural materials distribution and purchasing and storage and other dimensions and the whole production chain. Through the collaboration of these three aspects, the following purposes can be achieved:

(1) In the large-scale farmland environment, the collaboration between the agricultural machinery can realize the automatic optimal allocation operation between different agricultural machinery. In this way, the connection between operation lines can be guaranteed effectively, and the agricultural machinery efficiency and land utilization rate can be improved.

(2) According to the information of previous process, operation location and performance of agricultural machinery stored in the server, task allocation, operation path planning and independent operation alignment of agricultural machinery can be realized through data collaboration in different links. The seamless link of agricultural machinery in each link can avoid the rolling, leakage and harvest loss of machinery, thus improving the quality of agricultural machinery operation.

(3) The agricultural machinery operation information platform is used to establish the cooperative relationship between the up-downstream partners and the supply chain, through that, the demand quantity and time of agricultural supplies are predicted, and the procurement, warehousing, transportation and distribution of agricultural supplies can be carried out. Suppliers can prepare and deliver agricultural materials to the destination precisely to realize zero or less inventory of agricultural materials and solve a series of problems caused by agricultural materials inventory, such as warehouse construction, management costs, inventory maintenance, storage, multiple transportation and stevedorage costs, as well as inventory loss and deterioration.

In the traditional agricultural machinery management mode, only the “machine” problem needs to be solved. However, the multi-machine collaboration of intelligent agricultural machinery also needs to solve the problem of “people” and “things”, so as to realize the precise control, intelligent decision-making, monitoring and tracking of the whole process from agricultural material preparation, land leveling, intelligent tillage and consolidation, precise fertilization and sowing, precise management, harvest to storage and transportation of producing area. The multi-machine collaboration of multi-dimensional agricultural machinery affects all links of the agricultural industry chain, making many things in the agricultural field that could not be done in the past “become possible”.

3 Realization conditions of multi-machine collaboration in intelligent agricultural machinery

The multi-machine collaboration system of intelligent agricultural machinery involves multi-sector, multi-field, multi-disciplinary cross and integration, which makes it systematic and complex. The foundation and priority task of intelligent agricultural multi-machine cooperative system is the research of key theory and technology innovation. Nowadays, the research on multi-machine collaborative operation of agricultural machinery in China is mostly limited to the research on task goal planning and collaborative path optimization of single production link[20-22]. There is no collaborative research on agricultural machinery multi-machinery that comprehensively considers the collaboration among the agricultural machinery system and the external supply chain and the acquisition/storage chain in the agricultural production process, as well as the comprehensive planning of resources inventory such as agricultural machinery equipment, accessories and agricultural materials. In order to achieve the collaboration of the above three aspects, intelligent agricultural machinery should focus on data collaboration, process collaboration and organization collaboration. Only synchronous data collaboration, process collaboration, system collaboration, multi-dimensional multi-machine collaboration of agricultural machinery can play its due role.

3.1 Data collaboration

Digitalization is the basis of agricultural machinery intellectualization. The data collaboration of multi-machine collaboration of intelligent agricultural machinery not only requires the collaboration of data on different agricultural machinery in the same production link, but also requires the collaboration of data on agricultural machinery in different agricultural production links. Intelligent agricultural machinery and equipment carries the physical space of agricultural production, and data carries the information space of agricultural production. Data is not only the basis of agricultural machinery decision-making, but also the multi-machine collaborative communication language of intelligent agricultural machinery. If the problem of data collaboration is not solved, agricultural machinery will not be able to work. The collection of agricultural production data is multi-dimensional, not only structured data, but also more and more unstructured data, such as weather data, terrain and atmospheric data from satellite images. The forms of digital are also diverse, such as surveillance images and videos, sensor scalar data, etc. Agricultural production data is the data of the whole industrial chain. It is not only in agricultural production, but also includes agricultural production data of supply chain and storage chain before and after agricultural production. The data of supply chain and storage chain before and after agricultural production mainly include agricultural materials and agricultural products market data. The data in agricultural production mainly includes the following aspects:

3.1.1 Agricultural situation data

(1) Climate data, including atmospheric temperature and humidity, light, wind speed, wind direction, air pressure, rainfall, evaporation, etc.

(2) Planting geographical data, including planting varieties, area, geographical location, land size, etc.

(3) Soil moisture data, soil moisture, temperature, soil tension and conductivity, etc.

(4) Crop growth data and pest data, including crop plant height, stem diameter, leaf area, leaf angle, crown width, nutrient abundance, biomass, yield, pests and weeds.

3.1.2 Operation status data of agricultural machinery

(1) Common parameter data of agricultural equipment, including engine, power output, torque, slip rate, attitude, safety hazard information and so on.

(2) Tillage machinery operation parameter data, including attitude, position, depth, elevation, etc. The key premise to realize subsoiling operation is the precise detection of tillage depth.

(3) Operation parameter data of fertilizer and seeding machinery, including seed seeding amount, fertilizer flow rate, fertilizer blocking alarm, sowing depth, etc. The precise perception of the operating parameters of the fertilizing and seeding machinery

is the basis for the precise autonomous operation of the fertilizing and seeding machinery.

(4) Operation parameter data of plant protection machinery, including spray pressure, spray flow rate and spray rod attitude.

Operation parameter data of harvesting machinery: Due to the wide variety of harvesting machinery, this paper mainly takes the combined harvesting of rice, wheat and corn as an example to analyze. The operation parameter data of this kind of combined harvester mainly include cutting table load, detaching drum load, water content, flow rate, cleaning loss rate, entrainment loss rate, etc.

3.1.3 Data of supply chain

(1) Materials of agricultural: including seeds, fertilizers, pesticides, agricultural films, agricultural machinery accessories, etc.

(2) Agricultural products: including the variety, yield, water content and total harvest of harvested grains.

The value of data can only be realized when it is applied. As shown in Figure 3, data rules are established based on data scattered on different platforms and organizations. And put forward the data format standard, content standard, etc. Standardize data through format standards, content standards, etc. Connect data between different systems within the organization and between internal and external systems, and establish a data management platform. Through the data transmission channel, the internal and external connection of data among different organizations is realized and concentrated into big data. Finally, through the deep processing and full utilization of the data, the data can be empowered and driven to make decisions, e.g., using data for production planning, inventory management, job management, etc.

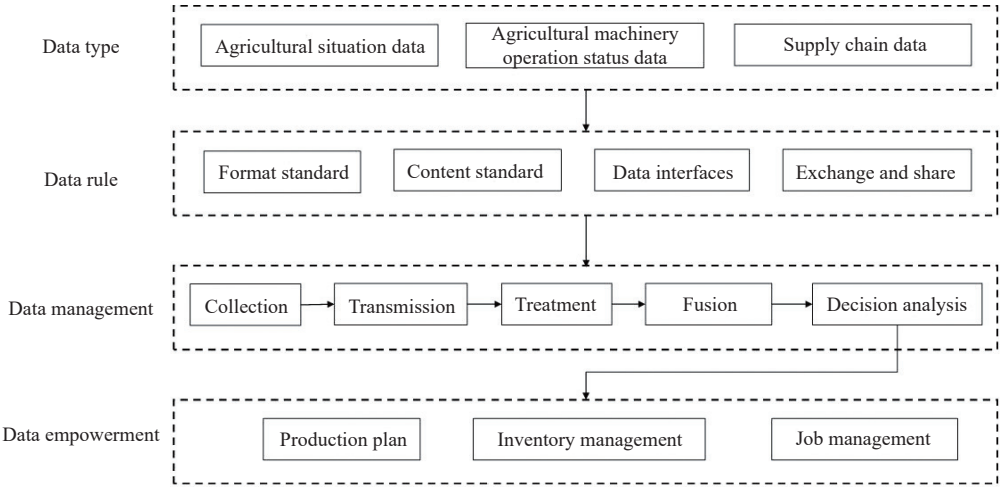

Figure 3 Structure diagram of data collaboration

3.2 Process collaboration

The multi-machine collaborative process of intelligent agricultural machinery is reflected in each process of agricultural production and the collaboration among the processes. It can not only realize the agricultural machinery configuration and multi-machine collaborative operation in each production link of cultivation, planting, management and harvesting, but also realize the collaboration between the processes of agricultural material preparation, land cultivation, planting, field management, harvesting, initial processing, storage and transportation of agricultural products. If process problems are not resolved, intelligent agricultural machines will not be able to perform any work cooperatively. Process collaboration needs to focus on the whole process of process planning (combing and defining planning), process operation (approval and monitoring of process operation) to process optimization (analysis, optimization and improvement of process). Process collaboration is the best combination of agricultural machinery and information technology. Carry data through the process, so that the data will all production modules and functions together. Process management makes agricultural production from the manager, the machine to the management process of each environment, so that the physical existence of agricultural production is eventually transformed into the existence of digital. The docking between processes requires the standardization of the process, so as to ensure that all the data before and after the process is provided to the greatest extent in decision-making. The process involves process nodes, time allocation, resource allocation and efficiency evaluation, etc. It is formulated by agriculture and agricultural machinery experts and executed by intelligent agricultural machinery.

For taking wheat harvest, wheat harvesting, threshing and transshipment operations require different agricultural machinery and equipment such as harvesters, grain trucks, and oil tankers to operate simultaneously[23-25]. The effective collaboration of these equipment need to address the following issues: 1) The time and place of oil replenishment. 2) The unloading time and place of the harvester. 3) The unloading time and place of the transfer vehicle. These problems need to develop processes, comprehensive consideration of equipment, accessories, agricultural materials and other resources inventory integrated multi-machine collaborative operation planning. Multi-machine collaborative operation planning includes key technologies such as operation mode, multi-dimensional collaboration, autonomous tracking technology, multi-machine AD hoc network communication, multi-machine automatic navigation, real-time monitoring of operation information and so on. Through the realization of intelligent configuration of agricultural machinery, intelligent monitoring of mechanical state, intelligent real-time scheduling, intelligent maintenance, etc., the precise and efficient management of mechanical operations is finally realized.

3.3 Organization collaboration

Organizational collaboration is to polish the diversified individuals of an organization into a compound and unified organic whole. Organizational collaboration includes the collaboration between different departments of the same organization (horizontal collaboration) and the collaboration between organizations (vertical collaboration).

Horizontal collaboration within smart farms refers to the

organizational model and collaboration of material supply departments, production departments, technical departments and planning departments. Horizontal collaboration connects through process, and focusing on the direction of process movement. Vertical collaboration focuses on the collaboration between organizations, such as the collaboration of means of production suppliers, logistics and agricultural products markets in the industrial chain. Informatization and intelligence make the organization level tend to flat, and the best way to achieve flat is platformization.

3.4 Systematic collaboration among data, process and organization

Multi-machine collaboration of intelligent agricultural machinery is a systematic engineering. Multi-machine collaboration of intelligent agricultural machinery is a system composed of multi-dimensional organizations. It mainly includes the autonomous collaboration between intelligent agricultural machinery within the agricultural machinery system, the configuration collaboration of intelligent agricultural machinery in the whole process of agricultural production, the collaboration between intelligent agricultural machinery system and external (production materials, accessories) supply chain, purchasing and storage chain, etc (Figure 4). The multi-machine cooperation of intelligent agricultural machinery is a complex closed system. Each organization as each other influence and depend on the component through a unified management mechanism to integrate into a multi-functional organic whole. The system collaboration focuses on solving the problem of 'thing', which is the highest requirement of intelligent agricultural machinery multi-machine collaboration. System collaboration is mainly formulated by experts, and then implemented by intelligent agricultural machinery and farm managers. The multi-machine collaborative system of intelligent agricultural machinery is the core soft power. The basic premise of multi-machine collaboration of intelligent agricultural machinery to play an overall role needs to achieve system collaboration. Meanwhile, the technical collaboration of the system can directly help to quickly achieve data collaboration and process collaboration. System collaboration is conducive to information sharing within and outside the organization and improving overall work efficiency. The future intelligent agricultural machinery system must be a composite system composed of human, machine and material. The physical manifestation of system collaboration is the interaction and working collaboration of human, machine and object. It not only relies on intelligent technology, but also must apply big data, cloud computation, Internet of Things, mobile Internet, blockchain and other advanced technologies.

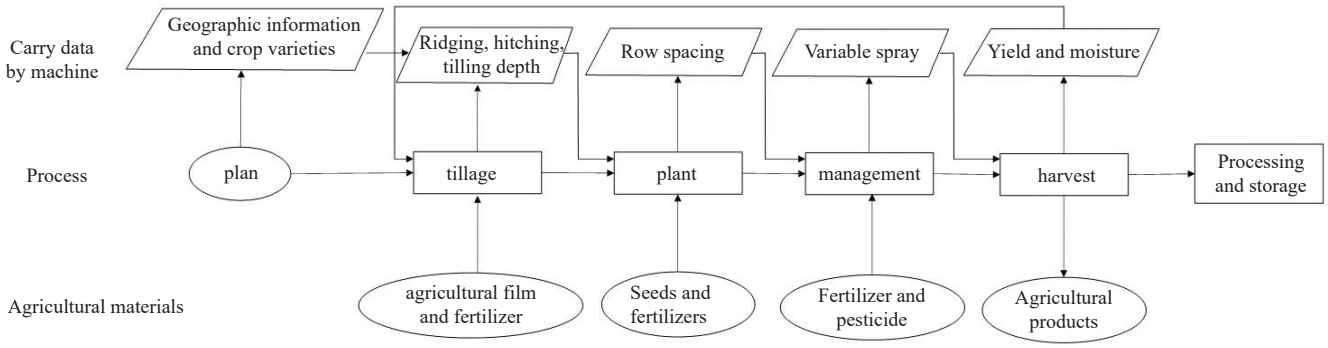

Figure 4 Flowchart of system collaboration

For agricultural materials zero inventory management, it is the same as other materials inventory management. The change of agricultural material inventory is closely related to supply market and demand market. The realization of zero inventory of agricultural materials is the three-dimensional collaboration of organization: 1) Responsiveness in sync with demand，timely response to changes in agricultural demand, agricultural market environment, agricultural market environment and consumer demand. 2) Sufficient and synchronous transmission capacity for logistics, information flow and capital flow. 3) With agricultural production, procurement, storage, transportation, distribution, sales and other links of business operation capacity, so as to establish a harmonious cooperative relationship with the upstream and downstream agricultural production and supply chain partners. Thus, zero inventory management is not isolated, but forms a closed-loop system with complex feedback relationships with other departments. In this system, each link of agricultural supplies demand application, planning, production and supply, procurement and storage, distribution and use, information platform construction and so on should achieve seamless link.

4 Precise and efficient production mode under the background of multi-machine collaboration of intelligent agricultural machinery

Precision agriculture production mode is a new concept and new form of agricultural development. It is also a fusion application of remote sensing network, sensor network, big data, Internet, cloud computing, artificial intelligence and other new generation of information technology and agriculture[24-27]. Precision agriculture production mode is a kind of soft thinking. The multi-machine cooperation of intelligent agricultural machinery is a new system to realize agricultural operation mode by using intelligent agricultural equipment technology. Precision agricultural production mode and multi-machine cooperation of intelligent agricultural machinery are mutually supportive. The development of precision agriculture is one of the goals to be realized by intelligent agricultural machine multi-machine collaboration. At the same time, the development of precision agriculture also needs the support of intelligent agricultural machinery technology. Moreover, the multi-machine collaboration of intelligent agricultural machinery is not only an important component of precision agriculture, but also an important carrier for the realization of precision agriculture.

In practice, the implementation of precision agriculture production mode is vague. It lacks the whole chain of the front and back end of agricultural production, from the preparation of agricultural materials to the production operation and then to the sale of agricultural products, as well as the complete systematic research on the realization of precision agriculture mode. In this paper, based on the idea of system research, the realization mode of precise and efficient agricultural production mode under the multi-

machine collaboration of intelligent agricultural machinery in agricultural production process (supply of biological data-agricultural production-agricultural products) is clarified. The data collaboration and organizational collaboration among different units and links in agricultural production system under process collaboration are analyzed. At the same time, the connotation, basic structure and key tasks of the multi-machine collaborative technology system of intelligent agricultural machinery under precision agriculture production mode are proposed. A multi-machine cooperative precise operation mode system of intelligent agricultural machinery is built, which integrates agricultural resources guarantee, data sharing, production decision and collaborative operation. It solves the problem that traditional research methods ignore the systematic thinking of precision agriculture production mode, and cannot coordinate the various links of precision agriculture production mode and coordinate multiple objectives. This study provides scientific support for the technical realization of multi-machine collaboration of intelligent agricultural machinery. It also provides systematic ideas and methods for the research of precision agriculture production development theory and application.

4.1 Zero inventory mode of agricultural materials under the background of multi-machine collaboration of intelligent agricultural machinery

Under the background of multi-machine cooperation of intelligent agricultural machinery, the front end of agricultural production mainly focuses on the supply of production materials, and achieves zero inventory of agricultural materials through data and organizational collaboration of intelligent agricultural machinery. The middle end of agricultural production focuses on intelligent agricultural machinery configuration and multi-machine collaborative operations in agricultural production links (tillage, plant, management, harvest), as well as collaboration between processes. It mainly includes the collaboration of agricultural preparation, land cultivation, planting, field management, and harvest. The back end of agricultural production focuses on the initial processing, storage and transportation of agricultural products.

4.1.1 Zero inventory for means of production and agricultural products

(1) Characteristics and necessity of zero inventory

Zero inventory is a special inventory concept, which is an important classification concept for industrial enterprises and commercial enterprises. Zero inventory refers to a very low or even zero storage of some or some items in the form of warehouse storage, that is, not keeping inventory[28]. The meaning of zero inventory can be understood from two aspects, one is the absolute meaning of zero inventory, and the other is the relative meaning of zero inventory. Especially, the commonly used is the relative sense of zero inventory, because the absolute zero inventory is impossible and unrealistic. Zero inventory can avoid a series of problems of warehouse inventory, such as warehouse construction, management costs, inventory maintenance, storage, loading and unloading, handling and other costs. At the same time, it can also avoid inventory occupation of working capital and inventory aging, loss, deterioration and other problems. The goal of zero inventory is to reduce the inventory as much as possible, reduce the cost input in the inventory stage, and then improve the utilization of capital and materials.

Agricultural materials preparation includes seeds, fertilizers, pesticides, mechanical parts, oil and other materials. Under the background of multi-machine collaboration of intelligent agricultural machinery, the types and varieties of crops planted in each plot can be checked through the final annual plan. Then, the yield distribution map obtained by last season harvester is used for grid variable fertilization analysis of each plot. Finally, a variable fertilization decision scheme is formed and recorded in the repository. Meanwhile, the sensors carried by intelligent agricultural machinery can monitor the state of agricultural machinery and give early warning, so as to determine the demand for agricultural machinery accessories. In addition, it can also be used for agricultural materials inventory (seeds, fertilizers, oil, agricultural machinery parts, etc.) for verification to determine the final demands for agricultural materials. Moreover, it can also predict the maturity time and output quantity of crops through the data collected by intelligent agricultural machinery, and connecting the market in advance to realize the immediate production and sales of crops.

(2) Realization conditions of zero inventory under multi-machine collaboration of intelligent agricultural machinery

The distribution of agricultural materials is an important link in the supply of agricultural materials. Agricultural products can only be arrived by quality, quantity and time through reasonable logistics distribution, so as to ensure the normal operation of agricultural production. Zero inventory management is not isolated, but has a complex feedback relationship with other departments. It can make demand applications, planning, production and supply, procurement and storage, distribution use, information platform construction and other links to achieve seamless. The change of inventory is closely related to supply market and demand market. When analyzing whether agricultural materials are suitable for zero inventory management, the following two aspects need to be considered:

1) Stability and standardization of agricultural demand

First, the characteristics of agricultural materials are important factors to be considered when implementing zero inventory management. In addition to external factors, the selection of zero inventory management objects is more affected by the characteristics of materials themselves[29]. Compared with manufacturing, agricultural production is seasonal and cyclical. Not only the production cycle is long, but also has the particularity in the inventory management. Agricultural production materials are mainly seeds, fertilizers, pesticides, agricultural films, and agricultural machinery accessories. They have the characteristics of many varieties of distribution, strong seasonality, and strong regionality. Moreover, they also have the characteristics of large volume, large weight, and concentrated use cycle. Secondly, the characteristics of material consumption are an important basis for the implementation of zero inventory management. Only by precisely grasping the characteristics of various types of material consumption can a reasonable inventory plan be determined without affecting the use of materials. For manufacturing, market demand determines production. At the same time, the need for means of production is also subject to the changing market. But for agricultural production, the agricultural production cycle is longer. After the production plan is determined, the demand for agricultural materials is relatively stable. And in the context of intelligent agricultural multi-machine collaboration, it can more precisely predict the use of agricultural quantity and use time. In addition, the standardization of materials also affects the inventory management of materials. Standard materials refer to materials with uniform specifications and models, not materials provided for specific customers and specific product uses. Standard materials easy to

implement zero inventory procurement and zero inventory management. For example, agricultural production materials, fertilizers, pesticides, seeds, etc. are mostly standard materials.

2) Key technical guarantee of zero inventory of agricultural materials under the multi-machine collaboration of intelligent agricultural machinery

The realization of zero inventory needs to have the ability to respond to demand, the ability to transmit information fully and synchronously, and the ability to operate in all aspects of agricultural procurement, transportation and distribution. Zero inventory management is based on information management. To achieve zero inventory management must first ensure smooth flow of information between enterprises and departments within the enterprise. For example, it can be realized through multi-machine data collaboration and system collaboration of intelligent agricultural machinery. The basis of establishing a multi-machine collaborative management system for intelligent agricultural machinery is the processing of massive data and efficient data. Intelligent agricultural machinery is not only production machinery, but also data collection equipment. In the process of production, intelligent agricultural machinery realizes the data collection of the whole production process. It includes vehicle data such as engine speed, oil pressure, water temperature and operation speed, as well as operation data such as operation area, operation track, tillage depth monitoring, seeding monitoring and yield monitoring, etc[30-32]. Multi-machine collaborative management system of intelligent agricultural machinery can integrate relevant data for scientific judgment and intelligent decision-making. It is also possible to adjust the way of working based on real-time updated monitoring data. If there is sufficient information reference basis, zero inventory management will be possible.

In the process of making production plan, we can precisely master the quality and quantity of land according to the historical data of agricultural machinery operation. Then, we can precisely and real-time provide a variety of crop prices, supply and demand, market dynamics and other information, which based on the Internet information query statistical analysis system. Finally, we can make planting plan according to the above data. When the plan is determined, we can predict the demand for seeds, fertilizers, pesticides, agricultural films and other agricultural materials in combination with the land situation.

In agricultural production, agricultural production is greatly affected by natural conditions. The moisture, growth, yield and growth process of crops in each season are different. However, we can achieve double precise measurement of agricultural production information and growth links through the storage data and cloud big data of intelligent agricultural machinery in the links of cultivation, planting, management and harvesting. Moreover, it can also predict the demand and demand time of agricultural materials, which can provide precise agricultural materials preparation for suppliers. In addition, the sowing information recorded by vehicle sensors can predict the type, quantity, time and other information of fertilizer demand, and provide production planning and operation data for agricultural materials suppliers and agricultural products markets. Finally, agricultural supplies suppliers can precisely deliver agricultural supplies when fertilizer is needed through online orders, instant delivery and other means, so as to achieve zero inventory. The geographic information system on intelligent agricultural machinery can not only realize the real-time positioning of geographic information, but also optimize the scheduling and distribution route of transportation vehicles, and formulate a reasonable distribution plan. Therefore, agricultural materials can be timely, fast and precise distribution.

The on-board computer can record the status of agricultural machinery in real time, such as location, speed, working status, energy consumption, oil volume, harvester granary status, etc. It can also know the position and status of each agricultural machine in real time, and then arrange the tanker to replenish diesel in a reasonable position. In addition, the on-board computer can also monitor the state of the grain storage bin of the harvester in real time, such as arranging the grain delivery vehicle to unload the grain at a reasonable place in time, and predicting the time of unloading the grain.

Intelligent agricultural machinery can predict and warn parts problems in advance, and make the demand for agricultural machinery parts from unpredictable to predictable. It can not only save the cost of inventory management, but also save agricultural time. Intelligent management of intelligent agricultural machinery can remotely monitor the operating conditions of agricultural machinery. It can realize fault warning, guiding maintenance and remote dispatching of agricultural machinery. Intelligent agricultural machinery can realize the reasonable selection of different specifications of agricultural machinery for different areas of cultivated land, and realize the best matching of agricultural machinery resources[33]. The monitoring technology of intelligent agricultural machinery can realize t the real-time monitoring of the condition of agricultural machinery itself, the operation state of machinery and tools, meteorological conditions and working environment. And according to the obtained information to guide agricultural machinery to adjust the operation plan in time, effectively reduce the agricultural machinery operation process failure, machinery damage, poor quality and other problems.

In summary, the comprehensive application technology of production and operation management, agricultural material supply service, agricultural product purchasing and storage service, network service and multi-machine collaborative operation, as well as information guarantee, realize the zero inventory of agricultural materials under the ‘multimachine-multidimensional’ collaboration of intelligent agricultural machinery, as shown in Figure 5.

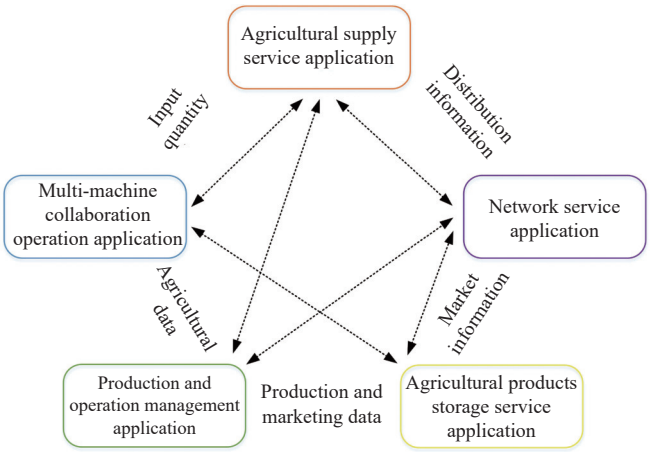

Figure 5 Technical application structure diagram of zero inventory under ‘multimachine-multidimensional’ collaboration of intelligent agricultural machinery

4.2 Multi-machine collaborative precision operation mode

Data collaboration and organization collaboration in agricultural machinery operation stage are mainly reflected in two aspects. On the one hand, intelligent agricultural machinery extracts

soil moisture and crop characteristics by collecting data information related to agricultural production, such as soil moisture, temperature, soil tension and conductivity, number of sowing, sowing position, crop growth and other information. Intelligent agricultural machinery uses the data collected by its own operation and big data for corresponding analysis to achieve precise positioning of crop demand, and then scientifically determine the management of water, fertilizer and medicine. On the other hand, intelligent agricultural machinery can realize multi-machine collaborative operations, such as automatic identification of field boundaries, automatic planning of crop paths, and scheduling of intelligent agricultural machinery equipment.

(1) Precision tillage

The precise leveling of farmland is an important part of precision tillage. The purpose of precision tillage is to provide a good seedbed for crop growth. By using the hydraulic system, sensor and electronic control system installed by the intelligent tillage machine, it can precisely control the position, ridge shape, furrow opening and working depth and other parameters according to the planting and agronomic requirements of the operation and soil moisture, so as to achieve precise and standardized tillage. The Beidou precise navigation equipment was installed on the agricultural machinery, and the path planning algorithm with the shortest turn-time was proposed by using the optimization method of motion planning, so as to realize the whole area coverage path planning of the field operation of the automatic guided tractor[34].

(2) Precision planting

Intelligent agricultural machinery perceives its position, surrounding environment and internal working state of machinery through visual system, sensor system and satellite positioning system. By using the relevant information collected on the agricultural machine in the tillage stage and the integrated Beidou and GPS navigation on the agricultural machine, the information is processed and analyzed to make decisions. On the one hand, intelligent agricultural machinery can achieve precise uniform speed driving in a straight line, precise control of the distance between round-trip driving, and precise control of the speed of each structure of agricultural machinery equipment, etc. On the other hand, intelligent agricultural machinery can precisely sow and transplant according to the characteristics of different crops. For example, intelligent agricultural machines can adjust row spacing, plant spacing, planting amount and soil cover depth by using soil moisture information and climate conditions. More importantly, intelligent agricultural machinery can collect data such as operation area and operation track to provide data for subsequent field management and harvesting.

(3) Precision field management

Field management mainly includes the management of water, fertilizer and medicine. Intelligent agricultural machinery can realize variable operation and automatic alignment in the field management stage by judging the growth environment and growth status of crops and combining the operation information collected in the tillage and sowing stage, and finally to achieve efficient and precise operation of intelligent agricultural machinery. More importantly, it can avoid the crushing and missing fertilization of crops.

(4) Precision harvest

Intelligent agricultural machinery is an intelligent precise harvest equipment, which can achieve timely harvesting and adjust the working parameters through the maturity and growth of crops information obtained by sensors installed on the harvester, such as grain yield, water content, loss rate and clutter rate sensors.

The vehicle information system can record the position, working state, energy consumption and the state of the granary of the harvester in real time. It can also arrange the tanker in a reasonable position to replenish oil. Meanwhile, the vehicle information system can monitor the state of the harvester granary in real time, so that the grain truck can unload grain at a reasonable place and time.

The collaborative operation of intelligent agricultural machinery can reduce the consumption of empty driving, detour, idle and waiting of agricultural machinery. It not only improves the efficiency of agricultural machinery operation, but also realizes the dynamic, collaborative, efficient and precise management of agricultural machinery operation.

4.3 Precision and efficient agricultural production mode based on three synergies

Figure 6 shows the precise and efficient agricultural production

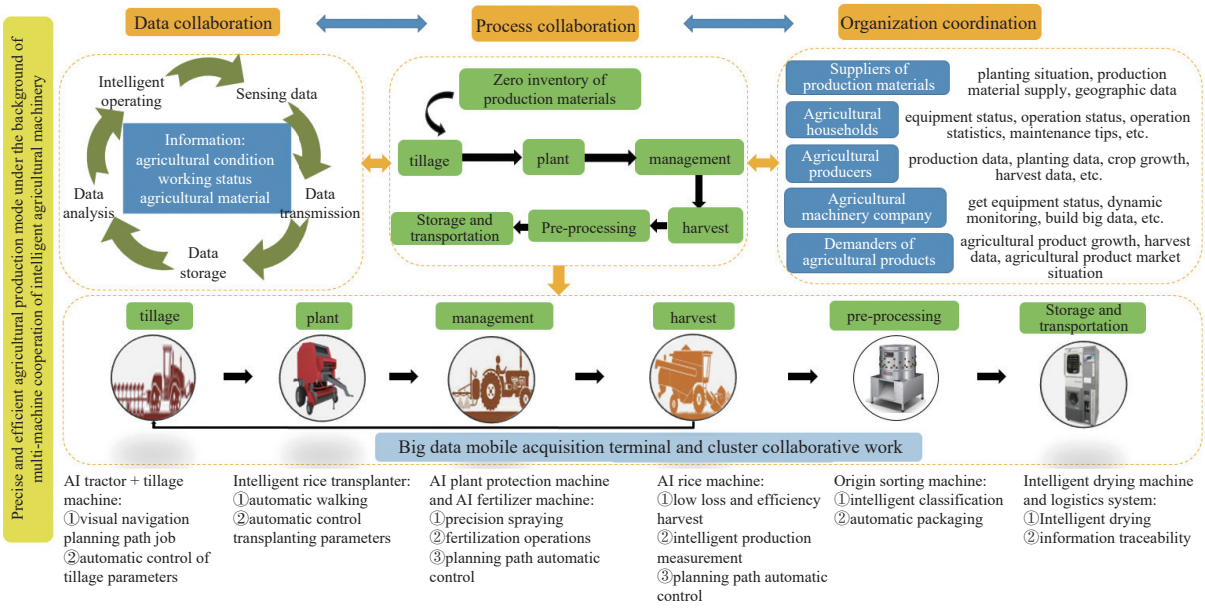

Figure 6 Precise and efficient agricultural production mode under the background of multi-machine cooperation of intelligent agricultural machinery

mode under the background of multi-machine cooperation of intelligent agricultural machinery. It can be seen from the figure that agricultural information, mechanical operation information and supply chain information are obtained through data, process and organizational collaboration. Then, analyze the data and control the operation of agricultural machinery. Meanwhile, the above information are further perceived through the intelligent operation process. Data collaboration drives the supply of agricultural materials such as seeds, fertilizers, pesticides, mechanical parts, and oilseeds. Suppliers deliver supplies in a timely and precise manner according to the types, quantities, times and locations of needed farm supplies. Data collaboration and organization collaboration can realize the precise operation of each production link of ploughing, planting, managing and harvesting. It can also achieve multi-machine collaborative work in the same link and collaborative work between processes. In summary, the multi-dimensional and full-chain agricultural machinery multi-machine collaborative technology model will greatly improve the efficiency of agricultural machinery, operation quality, land utilization, and reduce production costs.

5 Conclusions

In this paper, a new technology of multi-dimensional and full-chain agricultural machinery multi-machine collaboration is proposed, which comprehensively considers the agricultural machinery collaboration in the whole process of agricultural production, as well as the cooperation between the agricultural machinery system and external supply chain, storage and transportation chain, so as to achieve the purpose of zero inventory and precise and efficient production operations of agricultural materials. The connotation of data collaboration, process collaboration and organization collaboration are clarified, and the process of system collaboration and the realization conditions of new multi-machine collaboration technology are given. Moreover, the zero inventory mode and precise operation mode of agricultural materials under the background of multi-machine collaboration of intelligent agricultural machinery are proposed, and a precise and efficient agricultural production mode based on three collaborations is constructed. The results show that the multi-machine collaborative technology model of multi-dimensional and full-chain agricultural machinery will greatly improve the efficiency of agricultural machinery, operation quality, land utilization and reduce production costs.

Acknowledgements

This research was financially supported by Major Science and Technology Projects in Xinjiang Autonomous Region (Grant No. 2022A02005-5), the National Natural Science Foundation of China (Grant No. 32071905), and the Priority Academic Program Development of Jiangsu Higher Education Institutions (Grant No. PAPD-2023-87).

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