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Farming in the Era of Industrie 4.0

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Abstract

Consistent supply chain management across all levels of value creation is a common approach in the industrial sector. The implementation in agricultural processes requires rethinking the supply chain concept. The reasons are the heuristic characterised processes, the stochastic environmental conditions, the mobility of the production facilities and the low division of work.
In this paper we deal with how concepts of innovative supply chain management in the era of Industrie 4.0 could not only deliver a way to overcome said problems but also provide the foundation for the development of new forms of work and business models for Farming 4.0.

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Keywords: Supply Chain Management, Industrie 4.0, Smart Farming, Farming 4.0, Landwirtschaft 4.0

1. Introduction

Developments in digital technology have some known benefits for the agricultural business. For example, increasing the precision with which animals are monitored and fed, improving the management of arable land and controlling production. Several innovations, like sensor technology, positioning systems, digital image processing, data visualisation tools, etc., make this possible [1]. But for the farming sector, an efficient value creation across all levels along the whole supply chain is also of great importance. The support by a digitalised and comprehensive understanding of the reality enables new potential benefits for all involved partners. In order to achieve this, a holistic approach for digitalisation is necessary.

The abolition of the separation between the physical and the virtual world is the central paradigm of the Industrie 4.0 concept. The search for use cases of Industrie 4.0 is therefore driven by the identification of media breaks in the industrial everyday life. The core idea is ultimately the fusion of the real world and the corresponding digital models in digitalised systems along entire supply chains. Physical objects equipped with sensors and integrated intelligence become the main source of information along the value chain, as they communicate information about themselves and their environment to the relevant IT systems. This change in the way of collecting data along supply chains provides the foundation for the development of new forms of interaction and value creation, and delivers a baseline for business model innovations.

Methods of Industrie 4.0 have already been intensively investigated in some areas of agriculture, resulting in the emergence of terms like Agriculture 4.0 and Farming 4.0. However, the vision here is usually substantially reduced to applications in the field of precision farming and, to a lesser extent, to autonomous systems. Production planning and

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control, as well as the related logistic aspects, offer enormous potential benefits, and should therefore be brought more into focus.

This paper analyses the specific challenges facing farming along the agricultural supply chain in order to enable a successful implementation of Industrie 4.0 approaches. The resulting scientific value is the examination of how Industrie 4.0 approaches can be adapted to be applicable to the agricultural supply chain.

2. Agricultural value added processes

Agricultural processes can be mainly divided into the areas of animal and crop production. Crop farming processes include the cultivation of plants for the production of food, animal feed, and to be used as material for the generation energy or in further utilisation cycles. Inspection takes place in all phases of the vegetation cycle, covering soil preparation, sowing, crop protection, fertilisation, and harvesting.

The feed produced (or purchased) is then used in the animal production, also known as processing. Residues from animal production, such as liquid manure, are used in crop cultivation and partly for the generation of energy. It is then possible to speak, at least in part, of a nutrient cycle.

Almost all crop cultivation processes require coordination between machines and/or their interaction with the human operator. Processes may be sequential, such as baling straw bales, loading and transporting them; or be of a parallel nature, such as, for example, transferring crop from a harvester to a transport vehicle.

An application example characterised by a high need of coordination is the harvesting of silage maize. This procedure is of particular interest because the forage harvester has no bunker (i.e. buffer storage) and must be permanently overloaded during operation. If no transport vehicle is available, the partial shredding process comes to a sudden stop. Furthermore, the storage in the silo is of great importance in terms of feed quality. If one of the three sub-processes of chopping, transporting, and storing does not optimally adjust to the required capacity, either quality and time losses or avoidable costs are to be accepted. Quality, cost and time criteria influence each other.

In this context, methods of the Industrie 4.0 portfolio appear suitable for agricultural supply chains. Their contribution in terms of planning, monitoring, control, optimisation, and documentation can bring forth great improvements.

3. The supply chain challenge in agriculture

Agricultural supply chains differ in many aspects from their industrial counterpart. Different unifying and delimiting characteristics can be found.

Agricultural supply chains encompass the flow of products, knowledge, and information between agricultural stakeholder and consumers. They offer the opportunity to capture added value at each stage of the agricultural processes, marketing and consumption. However, because industrialisation can initially be considered unbiased, this should be reflected in the agricultural sector by strengthening the economic existence of farmers, improving the product quality, and reducing harmful environmental impacts.

The introduction and application of quantitative methods, as well as their development or adaptation, is essential for the management of supply chains. However, compared to industrial supply chains, quantitative methods in agriculture are less developed. Because of the complexity, that characterises the agricultural sector, experience-based heuristic methods play a key role.

Agricultural value creation takes place under strong environmental exposure. Stochastic events lead to a low deterministic behaviour, and result in unspecified process descriptions. The influence of weather and associated system behaviours contribute to the lack of predictability. Examples of this include soil and nutrient dynamics, photosynthesis activity or pest infestation. The modelling of these systems is the subject of agronomic research, but this can only provide an approximation to the real behaviour. Farmers must therefore deal implicitly with this supply chain uncertainty [2,3].

The technical equipment of agricultural enterprises has reached a level comparable to that of the industry, even exceeding it in some cases. The high degree of mobility of the production facilities makes planning and control more difficult than in industrial environments because boundary conditions are not always clear. Even the availability and bandwidth of wireless connections are a subject to disturbing influences, making a constant communication difficult.

Another key differentiator between agricultural and industrial supply chains is the extent of the division of work. Rationalisation effects through division of labour have decisively determined the development of the industrial production. By contrast, a small division of labour, analogous to craft, characterises agriculture. Agricultural supply chains recruit their workforce in a family environment and rely heavily on seasonal workers. These two situations make the demand of employees fundamentally different to the one in the industry. Employees in the industrial sector are highly specialised in their skill levels - from repetitive serial work to product specialists. In agriculture, a few employees carry out a large range of tasks. This requires a broad spectrum of knowledge and experience, as well as a high degree of specialisation. If these capabilities are not available, farmers have to rely on external services, such as contractors or consultants. Because agriculture is a small sector, unlike the manufacturing industry, typical tools such as ERP, MES and automation solutions have evolved in a completely different way. Quantitative working methods are only marginally established and the heuristic approach is still dominant.

Dealing with these challenges involves rethinking the current supply chain concept, the implemented business models, and the currently used technologies. In order to compete on the long-term in the age of Industrie 4.0, companies need to be able to rebuild their supply chain both internally (vertical process integration) and externally (horizontal process integration, in cooperation with external partners along the whole supply chain, such as farmers, wholesalers, and retailers). In particular, the horizontal integration of the value chain makes it possible to provide consumers with complete information about a product. These concepts are illustrated in the Fig. 1.

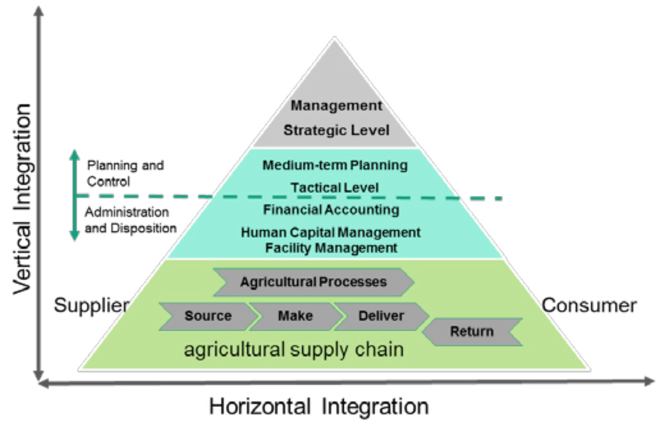

Fig. 1. Vertical and horizontal integration in the agricultural supply chain

4. Industrie 4.0 as a basis for coordination

The concept proposed by the Industrie 4.0 approach relies on creating an environment in which all elements are connected to each other in a seamless and effortless way. All devices (CPSs, cyber-physical systems) and functionalities are addressed as services, which constantly communicate with each other, and thus achieve a high level of coordination.

This ability to coordinate activities is fundamental in the area of supply chain management, where the optimisation normally requires the consideration of a great number of elements in constant competition with each other [4].

The benefits of applying Industrie 4.0 ideas to the supply chain challenges are therefore clear. Big, heterogeneous, and distributed environments can only benefit from the structure proposed. This is explained in the respective use-cases.

Existing approaches in the area of agricultural supply chains try to take advantage of technologies related to the digitalisation era. Perhaps the most mature one is Precision Farming, which makes use of positioning technologies (GPS) combined with the utilisation of additional sensors and the gathered data in order the increase the yield [5].

Further developments have also been made, leading to the emergence of concepts like Smart Farming, Agriculture 4.0, and Farming (known as Landwirtschaft 4.0 in Germany) [6]. Such approaches have dealt with many of the ideas of Industrie 4.0: increasing the amount of data gathered and used, improving the connection between devices, and creating appropriate environments for data processing (for example 365FarmNet). However, the focus is mainly on measuring and increasing the productivity of machines, installations, and fields. The logistic optimisation along the agricultural supply is either missing or considered as a simple communication problem [7], disregarding the complexity of the issues.

4.1. The requirements of agriculture

The project I40Demo, financed by the German Federal Ministry for Economic Affairs and Energy (BMWi), focuses on analysing the requirements of several application areas of Industrie 4.0, being the logistic aspect of agriculture one of them.

Within the project, the special requirements of agriculture were gathered and compared to the ones already recommended by specialists [8]. The results can be visualised in the Fig. 2.

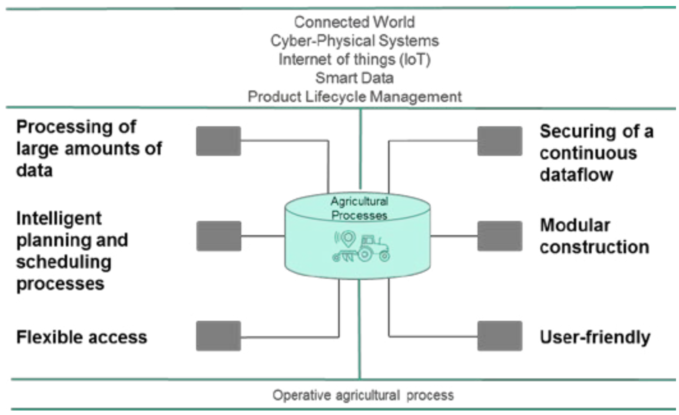

Fig. 2. Requirements of agriculture regarding Industrie 4.0

The production of agricultural goods is increasingly associated with the generation of data. But only a small part is currently used [9]. The efficient utilisation of data requires the ability to process large amounts of it, both structured and unstructured.

The connection of agricultural elements and components along the supply chain via the cloud using Internet of Things and Services (IoTS) platforms becomes of increasing importance. The Internet of Things and Services closes the media gap between the physical and the virtual world and enables the provision of value-added services based on a current and comprehensive understanding of reality.

As continuous data flows in agricultural regions cannot be assured, it is necessary to create compensation mechanisms and communication processes for delay tolerant networks. The application of adequate protocols and the adaptation of the technical configuration of the processes are good examples.

Therefore, factors like connectivity, flexible access, and modularity play a special role. This is logical, as machines and installations are not only distributed over large extensions, but can also be very heterogeneous. A modular construction of the information structure in the agriculture processes is important to combine function blocks flexibly. The system design has to allow enhancements and changes at runtime while not affecting the productivity of other subsystems.

Furthermore, in order to conceive and implement logistic improvements, the connection among the stakeholders in the agricultural supply chain is of great importance.

The current focus in the digitalisation of agriculture lies on the communication among machines and equipment (M2M); between machines, equipment and local administration software (e.g. yield measuring apps); and between machines, equipment, local software, and the machine or equipment providers. This is mainly achieved relying on the ISO 11783 (or ISOBUS) standard. Application examples of this approach are the ones implemented by CLAAS (with the already mentioned 365FarmNet platform) and John Deere (be able to service its machines remotely).

Nevertheless, the digitalisation of the information exchange within the agricultural supply chain has been greatly neglected.

Communications between farmers, vendors and clients are done mostly analogously, with the usage of e-mail, digital invoicing, and some rudimentary software in the best cases. With an increased degree of development, machinery rings already offer their services on platforms (marketplaces). However, the exchange of information is far from being standardised or automated.

Elements of Industrie 4.0 applied to agriculture should allow the coordination between the two existing environments: the internal and the external one (Fig. 3). This is achieved by means of platforms and the corresponding functionalities.

The aim is to develop a manufacturer-independent virtual interaction and communication environment that can be used collaboratively by both the internal and the external agricultural environment. The collaboration serves as an enabler for intelligent agricultural planning and control. This is achieved by using a combination of service-based functionalities.

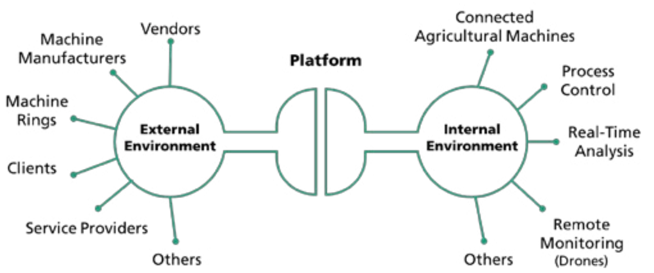

Fig. 3. The two environments of agriculture

In the following sections, two use cases are presented to show how Industrie 4.0 applications can be designed and applied in the agricultural application context, making focus on the benefits along the supply chain.

5. First use-case: high-end processes for agriculture

Taking the gathered requirements of the agricultural sector into account a new work structure is proposed, with its corresponding components. These are based on the known Industrie 4.0 arrangement for industrial production environments [10].

In this way, "high-end processes" are designed, in which a higher degree of coordination at all levels is possible.

The proposed structure (Fig. 4) presents three levels:

- Self-configuration level: This level comprehends the configuration of the machines, either within themselves (regulating their own work), or in direct coordination with others (e.g. autonomous positioning in relation to other machines). Here the proposed ACPSs (agricultural cyber-physical systems) represent machines, installations, and additional devices (e.g. sensors, drones, etc.). This level makes use of the "edge" approach: decisions are made locally within the devices, as no further coordination is necessary and response time is important. This is especially necessary due to the lack of stable communication networks on the field. Examples of applications are, for example, the consumption sensors mounted on moving machines that measure while driving, or the use of multi-spectral sensors on the sprayer boom of a tractor to estimate the nitrogen demand of the crop to be sprayed and to adjust the dosage. In this way, every machine is converted into an actor (being capable of making decisions for itself, like correcting the route) and a data source. This enables the optimisation of its own work, that of others (ACPs and functionalities), and across the whole supply chain (as made possible by the collaboration levels).

- Local collaboration level: This level is composed by the platforms that allocate the functions necessary for the administration of the local production environment (i.e. one farm). Here is where the analysis of the own production takes place (processing data from different sources). An application example is the usage of drones (ACPs) to detect areas where the presence of weed is problematic. This data can then combined with that of the yield of each area (using the corresponding platform functionality) in order to prioritise the application of herbicide. This can be done by other ACPs: an example is RIPPA, an agricultural robot developed at the University of Sydney, which is able to identify weeds and apply the fluid individually. Another platform functionality could use the generated data to manage the usage and supply of herbicide.

- Extended collaboration level: This level allows the collaboration between different actors in the agricultural supply chain. Each actor possesses its own platform and functionalities, which collaborate with each other. For example, the farmer's local platform knows when a machine is required; this is communicated to the machinery ring platform, where the usage of the machines is planned.

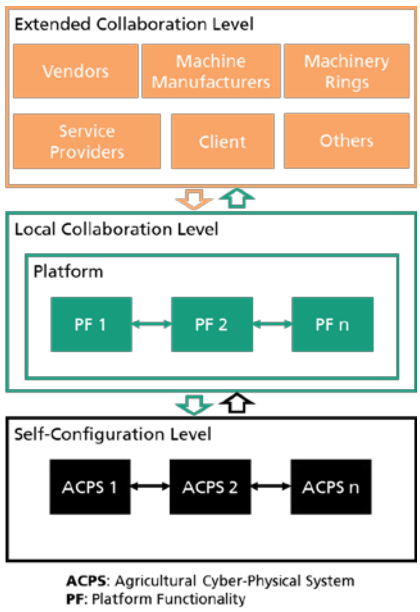

Fig. 4. Industry 4.0 collaboration levels in high-end processes of agriculture

The communication between all levels is possible and necessary. The main objective is the creation of a structure that is able to optimise itself [11]. The usage of advanced learning functionalities, based on machine learning, can support and expand this concept.

6. Second use-case: Mobile and autonomous robots in the agriculture

The application of Industrie 4.0 is based on the idea of "services" taking care of a specific task and coordinating their work in order to perform the desired process.

A further development of this approach would then require that the physical world recreates this way of work. The proposed implementation in the area of agriculture would then rely on the creation of devices that are able to offer the different steps of agricultural processes as services. In the praxis, this would mean breaking down the functions of agricultural machines into its constitutive functionalities.

The effectivity of such modular approaches has already been proved [12,13]. These tests, however, were based on optimising the local work of machines. The proposed idea extends the concept to the usage of swarms of autonomous machines, each with a different function, whose activities are coordinated by the services (platform functionalities) presented in the first use-case.

This would not only enable the optimisation of the work distribution, but also of the usage of such machines. The agricultural tasks could then be performed, with disregard of the scale (big or small), on a 24/7 basis [14].

An example for mobile and autonomous robots in the agriculture is the MARS (Mobile Agricultural Robot Swarms) research project. In an EU funded joint work of the Ulm University of Applied Sciences, AGCO, and Fendt an approach is being developed for autonomous farming operations by means of a coordinated swarm of robots. Project focus is the usage of low individual intelligence, meaning that each robot is equipped with a minimum of sensor technology. In this way, low cost and energy efficient system are achieved that are able to provide scalability and reliability for agricultural processes. The robot swarms are orchestrated by a central entity that is responsible for path planning, optimisation and supervision [15].

A similar direction is pursued by the Bosch startup Deepfield Robotics with the development of BoniRob. Based on the enterprise's own adaptable multi-purpose robotic platform, the modular approach of this autonomous agricultural robot allows it to adapt to many kinds of operations on the field.

7. Agricultural business models

The described digital transformation generates an improved information base along the agricultural supply chain and serves as an enabler for innovative agricultural business models. The design of these business model innovations require the combination of economic benefits with a sustainable agricultural approach for humans, animals, and the environment.

In order to prepare the business models for the digital change, the starting point should be the consideration of the existing ones, of the customer demand, and of the whole supply chain, including the stakeholders. From this point of view, there are three basic approaches that can be derived: internal, external, and direct [16].

The internal approach means in the agricultural context that products, services, and the internal value creation will be transformed. This includes the conception of new digital services (such as apps that make the internal agricultural value creation processes transparent for the customer), the expansion of existing product offerings on digital platforms (such as online direct sales of the agricultural products), or the use of technologies to reduce costs at all levels of the own value chain.

The external approach to digitalise agricultural business models involves digitally transforming channels, customer relationships, and the collaboration with partners. The result is the transformation of the completely agricultural supply chain. This includes using tracking and analytics tools to analyse customer-buying behaviour; or using multiple and integrated channels, such as smartphones and social media, to enhance the customer experience.

The direct approach means that both paths are taken in parallel. The business model is then digitally transformed in all dimensions.

Another advantage derived from the availability of agricultural data is the utilisation of central databases. Information on which regions and conditions (e.g. weather, type of land, and fertilizer) provide the best yields is an extremely valuable information for successful agriculture ventures.

The new ways of collaborating along the agricultural supply chain enable the development of synergy and symbiotic effects between the stakeholders. This ensures the creation of precious competitive advantages for all partners involved.

8. Conclusions and further work

There is a social consensus that agriculture should not be industrialised. Since industrialisation can be viewed initially in a neutral way, there is a need to consider how it can strengthen the existence of farmers, improve animal welfare and product quality, and reduce harmful effects on the environment. The development or adaptation, introduction, and application of quantitative methods appears to be essential to achieve this goal.

Technological solutions provide an important contribution towards transforming the challenges of agricultural supply chain management into opportunities. Apparently, simple technologies such as Bluetooth, GPS or RFID, combined with the communication between humans and agricultural machinery at all levels of collaboration, make it possible to create a self-optimising agricultural supply chain structure.

Embedded in an innovative agricultural management platform, these technologies can be easily deployed and used by all involved stakeholders.

Consequently, a modern farm produces data aplenty. But it requires interpreting and for that, information technology is essential.

However, new technologies and software to digitalise the agriculture business cannot solve all challenges of the digital transformation along the supply chain alone. Infrastructure, further training and qualifications, an adequate structural and legislative operating environment, and willingness to implement new technologies are also crucial. For Farming 4.0 to work, a modern telecommunications infrastructure in rural areas is essential. In addition, the ability to utilise structured and unstructured data along the completely agricultural supply chain will prove essential for a successful transformation of existing agricultural processes towards farming in the era of Industrie 4.0.

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