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From Industry 4.0 to Agriculture 4.0: A Framework to Manage Product Data in Agri-Food Supply Chain for Voluntary Traceability

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Abstract**—**Agri-food value chain involves various stakeholders with different roles. All of them abide by national and international rules and leverage marketing strategies to advance their products. Food products and related processing phases carry with it a big mole of data that are often not used to inform final customer. Some data, if fittingly identified and used, can enhance the single company, and/or the all supply chain creates a math between marketing techniques and voluntary traceability strategies. Moreover, as of late, the world has seen buying-models' modification: customer is careful on wellbeing and food quality. Food citizenship and food democracy was born, leveraging on transparency, sustainability and food information needs. Internet of Things (IoT) and Analytics, some of the innovative technologies of Industry 4.0, have a significant impact on market and will act as a main thrust towards a genuine '4.0 change' for agriculture. But, realizing a traceability system is not simple because of the complexity of agri-food supply chain, a lot of actors involved, different business models, environmental variations impacting products and/or processes, and extraordinary climate changes. In order to give support to the company involved in a traceability path, starting from business model analysis and related business process a Framework to Manage Product Data in Agri-Food Supply Chain for Voluntary Traceability was conceived. Studying each process task and leveraging on modeling techniques lead to individuate information held by different actors during agri-food supply chain. IoT technologies for data collection and Analytics techniques for data processing supply information useful to increase the efficiency intra-company and competitiveness in the market. The whole information recovered can be shown through IT solutions and mobile application to made accessible to the company, the entire supply chain and the consumer with the view to guaranteeing transparency and quality.

Keywords**—**Agriculture 4.0, agri-food supply chain, Industry 4.0, voluntary traceability.

I. Introduction

INDUSTRY 4.0 stems from the 4th industrial revolution and is defined as a process that leads to fully automated and interconnected industrial production [1]. To date, this revolution is linked with economic development of the manufacturing sector, but it carries with it an evolutionary potential that is undoubtedly scalable. Some of the technological phenomena typical of Industry 4.0, such as the IoT and Analytics, are the most relevant in terms of impact on the market and will act as a driving force towards a real '4.0 transformation' during the next 10-15 years. With a view to transferring technological dynamics to the agri-food Industry, a multi-layered methodological and technological framework was developed, capable of enabling the entire agri-food chain to implement a voluntary traceability system based on the application of IoT, Analytics and technology based social interaction.

The innovation of this system is of multiple values. Through the adoption of the Industry 4.0 matrix technology by the agricultural sector, in fact, a multimodal communication model aimed at the efficiency of production processes and the focusing of the new needs of the current consumer as Food Citizen [2] is guaranteed. In recent years, the world has witnessed a change in purchasing patterns, involving the consumer who is increasingly attentive to his health and to the quality of the food he buys [3]. Starting from the assumption that people are not consumers but citizens, the concept of Food Democracy is born, in which food is not considered a consumer good but a right and, as such, must be safe and nutritious, as well as product and enjoyed in respect of environment and of those who cultivated it [4]. Intercepting this need with a view to market opportunities leads the agri-food business to embrace the quantity-quality duo and to undertake sustainable production paths and voluntary traceability tools able to witness these choices. Voluntary traceability has two main objectives: food safety and quality [5]. With regard to food safety, therefore, to specific production rules and controls, voluntary traceability allows a higher level of safety to be achieved than that of mandatory traceability. For example, in the case of food contamination, having a separate management of the batches within a production chain, allows the company to collect only the dangerous lots limiting damages and economic losses [6]. With reference to food quality, voluntary traceability is a guarantee of the achievement of quality standards [7]. The adoption of rules and controls allows, in fact, to reduce the costs of non-compliance and to achieve a good degree of differentiation of the product with which to go on the market [6]. The adoption of these systems will be successful until the end, when all the actors of the same value chain will be adopted as they will benefit from an increase in the competitive advantage and a greater level of compliance with the requests of the market.

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The paper will be structured as follows: in the introductory section, the scenario analysis and the literature are reported. In the second section, the paradigm of Industry 4.0 and how Agriculture can use it are discussed. In the following, in Section III, the issue to manage product data along complex value chain, as agri-food supply chain, in order to obtain traceability information is debated. Finally, with a view to supporting the company in the implementation of a voluntary traceability system, that leverages the principles of Industry 4.0, a multilayer methodological and technological framework is proposed.

II. Principles of Industry 4.0, Agriculture 4.0's Servant

In the era of the 4th industrial revolution, the use of digital technologies, thanks to the integration of data and the connection of resources, will allow the creation of an efficient and sustainable company system.

The transfer of the Industry 4.0 paradigm to the agri-food Industry will result in a consequent and natural transfer of benefits to this industry. The use of digital technologies will allow to act concretely on the factors of production, catalyzing the innovation process already introduced by the precision agriculture paradigm. In fact, wanting to reconstruct the path of technological evolution that has affected the agricultural industry, we can identify a few salient points that see in the 'green revolution' of the 70s the mechanization of a previously manual sector and the subsequent use of the first technologies of agriculture precision in the 90s [8]. These technologies have then evolved to the present day becoming increasingly sophisticated and based on digital, constituting, about manufacturing sector, the actual Industry 4.0 technologies. From that current scenario emerging that "Industry 4.0 is a train that cannot be lost", as stated by the Director of the Industry 4.0 Observatory of the School of Management of the Milan Polytechnic on the occasion of the presentation of the conference 'Industry 4.0, the big opportunity for Italy'. According to analyzes conducted by the Observatory in 2017, this "train" is already traveling with a growth rate of 25%, generating a monetary value of 1.7 billion euros.

The macro-phenomenon Industry 4.0, appears to be supported by a series of very clear technological phenomena [9]:

- 63% of the market generated by Industry 4.0, i.e. about 1 billion Euro, is directly connected to Connected Factory and IoT;
- 20% of the market, worth € 330 million, is represented by the Industrial Analytics;
- At about 9%, reaching a value of € 150 million, we find an important phenomenon such as Cloud Manufacturing;
- 8%, for 120 million euros, intercepts the Advanced Automation that includes autonomous and collaborative production and handling systems, robotics and collaborative robotics;
- About 1%, for a value of 15 million Euro, is related to the Advanced Human Machine Interface which sets up the role of viewers for augmented reality, 3D scanners, wearable and new human-machine interfaces as touch displays as shown in Fig. 1.

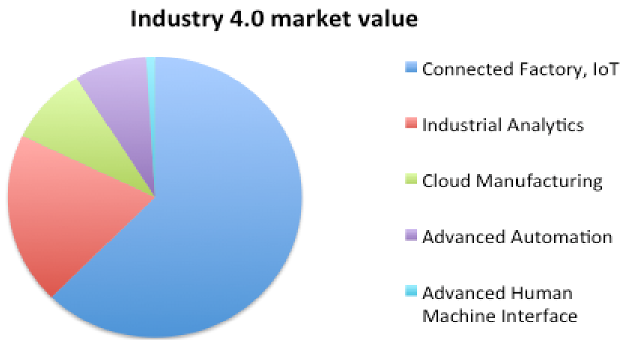

Fig. 1 Breakdown of the market value attributed to Industry 4.0 (data from the 2017 research of the Industry 4.0 Observatory of the Milan Polytechnic)

The application of the principles of Industry 4.0, best represented in the Smart Factory [9], is perceived not only as a true element of differentiation between companies, but also as an impetus for sustainable improvement.

Smart factories, suppliers of intelligent products and / or services connected to the Internet, collect and analyze data coming from intelligent products and their intelligent applications [10].

Data analysis allows companies to better define market behavior and customer needs, and indirectly suggest to provide them with new and /or more sustainable products and services. That represents an evolutionary potential for the company, without doubt scalable. The expected innovation is therefore traceable to at least three areas:

- The Smart Factory, or in this specific case, the Smart Farm, with reference to production, logistics, maintenance, quality and safety of the company;
- The Smart Supply Chain with reference to the management of flows (material and immaterial) between the various actors in the supply chain;
- The Smart Lifecycle with reference to the world of product development and management of its entire life cycle.

All implemented through IoT applications, Analytics, Cloud platforms, etc. These innovations will guarantee the sector higher incomes thanks to the possibility of obtaining higher production yields and lower costs and above all lower environmental impact and greater food safety for the consumer.

III. Product Data Managing through Agri-Food Supply Chain for Voluntary Food Traceability

The agri-food supply chain is the set of activities and companies that contribute to the supply chain of a foodstuff, starting from raw materials and inputs and arriving until the delivery of the product in the hands of the final consumer [11], activities in fact attributable to the production, transformation and marketing (packaging, distribution and selling) phases. In particular, all companies related to the economic sector of agriculture, breeding, forestry, forest areas, fishing and aquaculture carry out the production phase. Conversely, the transformation phase mainly concerns the food, beverage and tobacco industries. The last phase, that of marketing, involves trade (retail and wholesale) and catering [12]. The three phases are supported by external factors involved in transport, logistics, quality control and protection, supply of raw materials, packaging, labeling, marketing, communication, promotion, consulting, analysis, import and export, financial activities, regulation [12], [13].

The result is an articulated network of actors that puts at the center of the relationship the act of consumption [14], actors capable of acting on the final product and to which to impute the related responsibilities on the same.

The expected innovation in terms of Smart Supply Chain is therefore strongly linked to the possibility of modeling this network, identifying actors and processes, and activating inter-company information flows to the benefit of the quality of the product and of company sustainability, effectively embracing the theme of voluntary traceability of supply chain. An absolutely complex issue due to the complexity of the agri-food chain that sees products with highly different production processes and different business models lead the supply chain to contract and expand depending on the case. This situation poses a further obstacle to the possibility of creating a standard traceability model capable of operating in the same way and using the same tools in all agri-food contexts. In general, the concept of food traceability refers to the possibility to trace and then follow the food product during all its transformation phases [15], [16] and therefore to the possibility of connecting all the product information along the Supply Chain.

According to Golan et al. [17], a traceability system refers to three main characteristics:

- Amplitude, with reference to the amount of information that the system can memorize;
- Depth, with reference to the number of sectors involved in the agri-food Supply Chain;
- Accuracy, with reference to the analysis unit referred to the tracking activity.

The use of Industry 4.0 technologies would in fact improve the action capacity of a traceability system for each of its characteristics. In fact, through the logic of IoT and Cloud Computing, it is possible to increase the depth of the system by capillary monitoring every actor in the supply chain network. The use of sensors applied in production, processing and marketing environments offers an improvement also in terms of precision, increasing in fact the detail of the collected track. The application of Big Data and Analytics techniques is not only able to increase the breadth of the system, but will allow to create added value from the data collected at various levels:

- In - service company, offering the individual operator the opportunity to make their work more efficient,
- Inter - company, offering a continuous monitoring and improvement tool to the entire supply chain.

That could offer the final consumer more information, which would benefit from the product data guaranteeing quality and food safety. It can be deduced that if for the manufacturing sector every phenomenon of Industry 4.0 has the characteristics to generate value as characterized by standardized decision models, for the food sector this cannot happen.

There are many factors that make the decision-making models of the agri-food Industry unpredictable and non-standardized: different business models, environmental variations impacting products and/or processes, and extraordinary climate changes. To address these issues, we need to imagine an integrated system that takes into account more technologies related to Industry 4.0, considering at the same time [18]:

- need for low-cost and pervasive connectivity;
- advances in storage and data exchange;
- adaptable and accessible tools;
- innovative business models and partnerships;
- application for agricultural information services.

IV. The Proposed Framework

The agri-food industry shows numerous actors who perform various activities within the value chain, following national and international regulations and using marketing strategies to promote their products.

Often, information related to the product and the processing phases is not appropriately used to improve company and network efficiency or to create market strategies based on voluntary transparency and traceability policies.

A lot of information about the product is present and codified within the organizations that operate in the agri-food network in different places and formats [19], [20], other times the knowledge related to the product and its processing is present in the implicit knowledge of workers. However, it often happens that such information is not collected, stored, analyzed and used. The challenge is therefore to monitor any activity that can affect the quality and safety of the food product, collect data and strategic information in a more or less automatic way, and derive value from it.

With a view to support the company in the implementation of a voluntary traceability system that leverages the principles of Industry 4.0, a multilayer methodological and technological framework is proposed (Fig. 2).

Considering the complexity of the sector (number of actors, diversity of business models, variety of products and production techniques), the framework assumes that, in order to implement a traceability system, it is necessary first to analyze the business model adopted and then identify and model the processes that affect the product.

Process modeling can be done using BPM - Business Process Management techniques. In particular, through the use of the BPMN modeling language - Business Process Management Notation [21], it is possible to identify, for each task of a process, who executes the same, therefore, the actor who holds the information in the network. For each task, it is also possible to determine:

i. which information is useful for voluntary traceability and

ii. the tools, which in IoT perspective, can collect such information.

In particular, reference can be made to various types of physical and chemical sensors capable of monitoring the quality of air, water and soil in production environment, obtaining information on the salient phases of the product transformation, or monitoring the its transport conditions. Further information can then be 'recovered' from company software and from mechanisms that allow to transform the tacit knowledge of the operator into explicit knowledge [22]-[24], such as the use of IT applications for the collection of tacit information during the production, transformation, distribution and consumption phases of the product.

The real strength of the voluntary traceability system will then be the creation of a big-data platform where all the collected data will be merged, maintaining its paternity with respect to the supply chain operator and traceability towards the products.

All the collected data will be processed by specific Analytics techniques and by IT and mobile applications made accessible to the company, the entire supply chain and the consumer with a view to guaranteeing the benefits described above.

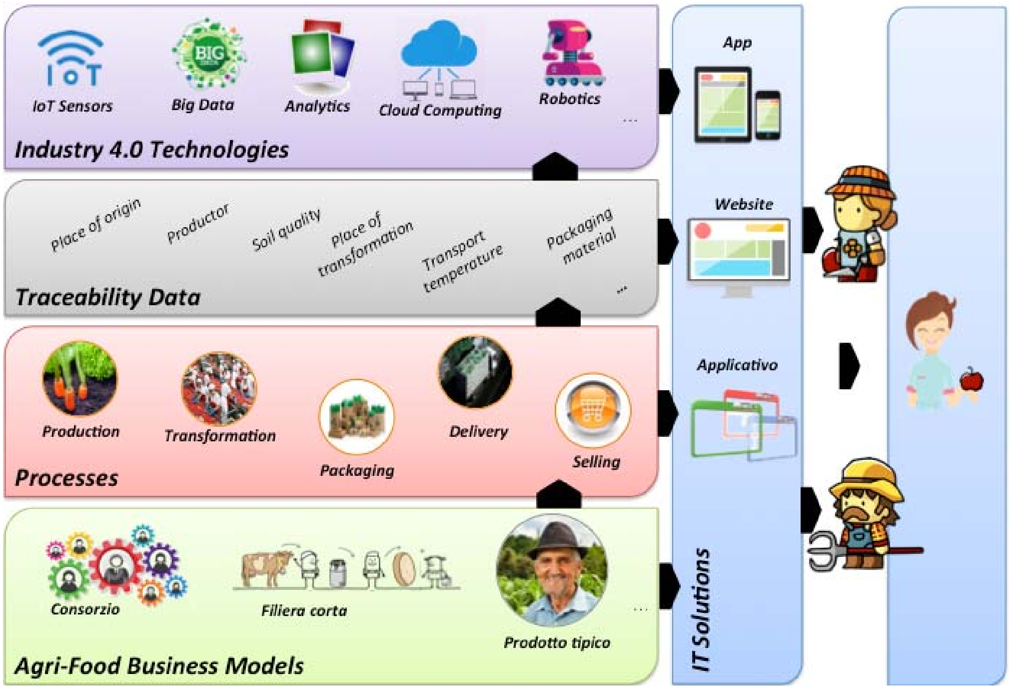

Fig. 2 Framework for the definition of a voluntary traceability system

Particular attention is therefore placed in addressing the problem in a modular way, developing solutions that fit the specific operating context and at the same time allow the company a gradual adoption, favoring a distributed investment path and an adequate training for the use of new solutions.

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