IoT adoption in agrifood operations:
A conceptual model for technology transference

Alvaro Augusto Dossa< alvaro.dossa@northampton.ac.uk >
The University of Northampton

Luciano Batista
The University of Northampton

Andrew Gough
The University of Northampton

Abstract

The agrifood sector has historically been quite receptive of new technologies and the Internet of Things (IoT) is no exception. These technologies have great potential to improve the sustainability of the sector, particularly in the farming context. The adoption of technologies depends on factors, such as costs, perceived gains, risk reduction and easiness of use. Thus, the diffusion of new technologies is not straight forward. Given the potential benefits of IoT to farm operations, this paper proposes a conceptual model to address its adoption issues, under a technology transfer perspective.

Keywords: Internet of Things, Agrifood operations, Technology transfer.

Introduction

Technological innovations such as steam engines, artificial insemination, genetic editing and nanotechnology, have been historically well received in the overall agrifood sector, despite some resistance to adopt recent advancements in the fields of biotechnology and genetically modified organisms (GMOs).

According to Brewster *et al.*(2017), the adoption of information and communication technologies (ICTs) in this sector is relatively low, but the adoption of Internet of Things (IoT) technologies has great potential to improve supply chains - from farm to fork – in terms of food safety, reduction of inputs and food waste, and overall sustainability. Other benefits of technologically enabled sustainable practices in the agrifood sector can also be identified in the literature, with a special consideration on farmers and farm operations (Sørensen *et al.*, 2010; Sorensen *et al.*, 2010; Jayaraman *et al.*, 2016), which are the main focus of this paper.

The adoption of technologies in agriculture it not a simple issue. It must take into account other factors in terms of decision making. Barriers such as available infrastructure, consistent supply and support for the technology, installation and maintenance costs, and so forth, must also be considered by the stakeholders involved.

The adoption of innovations is not only an investment decision that consider costs and expected financial gains, but also the risk perception, personality traits, expected operational advantages, among others (He and Veronesi, 2017; Asrat *et al.*, 2010; Suri, 2011).

For this paper, 'technology' is considered in its wider sense. That is, technology as 'applied knowledge to solve a problem' and therefore encompassing not only ICT, but also machinery, managerial practices, know-how, etc. necessary to its operationalisation. In this sense, when considering technology transference (TT) and adoption, we draw from literature broader than ICT technologies adoption, such as grain varieties or managerial practices.

In order to make smart farming, that is, the use of smart technologies in the farming context, more widespread worldwide, and in a more efficient way, the TT process must take into account for benefits (drivers), barriers of the technology and the factors affecting decision-making, such as risk aversion and institutional support, and plus others described later in the paper, that might influence technology adoption. This paper proposes a conceptual model for IoT promoters – institutions that develop and/or commercialize IoT technologies -and organisations interested in making IoT available and adopted by farmers.

This paper draws upon relevant literature on technology adoption and transference in agriculture, with particular focus on IoT in the agrifood sector. Drivers and barriers of IoT adoption are identified and real-life agribusiness cases are used to illustrate theoretical aspects of the model. The paper is conceptual, developing the theoretical basis and a practical technology transference assessment tool to support following empirical research in the OM field. It is structured as follows: Internet of Things (IoT) in agriculture; Examples of IoT application in farming operations; Farmers Technology Adoption; Conceptual Model; Conclusion; References.

Internet of Things (IoT) in agriculture

An in-depth analysis of both the history and different definitions if IoT can be found in Atzori *et al.* (2017). However, for this paper, we use the proposed definition for IoT given by Bogataj *et al.* (2017, p. 115): "*the inter-networking of physical devices (things) that enable them to collect and exchange data*". As expressed previously, we will use the term 'smart farming' as the usage of IoT in farming, even though some authors tend to consider the inclusion of Big Data analytics and cloud services together with IoT for it to be understood as smart farming (Kulatunga *et al.*, 2017; Jayaraman *et al.*, 2016)

IoT in agriculture is a development of the broader and more commonly known concept of 'Precision Agriculture', which is the use of techniques and technology to increase crop production by using sensors, satellite imaginary, GPS, and other similar devices in order identify variances and changes in plants, soil, wind, water, etc. and to assist in better decision making for the farm(Karim *et al.*, 2017; Embrapa, 2018; CEMA, 2018).However, such concept does not consider the interconnection of devices using ICT, and therefore, does not consist of IoT per se.

The use of IoT in farming is a new and expanding phenomenon, but several authors (Bogataj *et al.*, 2017; Granell *et al.*, 2016; Jayaraman *et al.*, 2016; Kulatunga *et al.*, 2017) have published works detailing smart farming applications in agrifood operations. We build upon those and others works, and use the classification of Brewster *et al.* (2017) - with its potential applications as well, to demonstrate the opportunities of use of IoT in agrifood operations, as demonstrated in Table 1. The agricultural domains presented by Brewster were selected given the operational similarities and differences between the domains, such expected shelve-life, short versus long production chains, among others (e.g. grains are normally non-perishable commodities part of a highly industrialized production chain, while fresh fruits are perishable and can be consumed *as harvested*). The potential applications presented here are not to be taken as all-encompassing and other uses of IoT not presented in the following table are also possible.

Table 1 – Potential applications of IoT in the agrifood sector

Agricultural domains	Application	Source	Benefit
Dairy	Cough monitor	Brewster et al. (2017);Marković et al. (2015)	Labour and risk reduction
	Fertility optimization		Efficiency gains
	Pasture management		Efficiency gains and cost reduction
	Toxic gas level and dust/particle monitoring		Social and environmental risk reduction
	Antimicrobial usage/disease risk management		Risk and cost reduction
	Environmental monitoring	Granell et al. (2016); Talavera *et al.*(2017); Marković *et al.*(2015)	Cost, labour and environmental risk
	Food value chain traceability	Tian(2017); Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Efficiency gains, social and environmental risk reduction
	Individual livestock tracking	Brewster et al. (2017); Kulatunga et al. (2017)	Efficiency gains, labour and risk reduction
Arable Crops	Disease and pest monitoring and control	Jayaraman et al. (2016); Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Efficiency gains, labour, risk and cost reduction
	Within-field management zoning	Brewster et al. (2017); Marković et al. (2015)	Efficiency gains
	Precision crop management		Efficiency gains
	Satellite/aerial imagery for biomass & harvest monitoring		Efficiency gains and risk reduction
	Precision machinery navigation		Efficiency gains and cost reduction
	Variable rate application of all inputs		Efficiency gains and cost reduction
	Environmental, soil and fertilization monitoring	Jayaraman et al. (2016); Granell et al.	Cost, labour and environmental risk

		(2016); Talavera et al. (2017); Marković et al. (2015); Marković et al. (2015)	
	Irrigation control	Jayaraman et al. (2016); Talavera et al. (2017); Marković et al. (2015)	Cost, labour and environmental risk reduction
	Big scale agricultural studies		Efficiency gains, labour and cost reduction
	Food value chain traceability	Tian(2017); Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Efficiency gains, social and environmental risk reduction
Fruits	GreenHouses micro-climate control	Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Efficiency gains
	Soil monitoring/improvement for healthy fruits		Labour reduction and efficiency gains
	Fruit disease and pest prevention		Risk reduction
	Satellite/aerial imagery for yield estimation		Efficiency gains
	Localized crop harvest info extraction		Efficiency gains, labour and cost reduction
	Post-harvest loss prevention by calculation of remaining shelf life and rerouting	Bogataj et al.(2017)	Efficiency gains, risk and cost reduction
	Automatic requests from end-consumers fridges for retail stores and/or producers		Efficiency gains
	Environmental, soil and fertilization monitoring	Jayaraman et al. (2016); Granell et al. (2016); Talavera et al. (2017); Marković et al. (2015)	Cost, labour and environmental risk
	Irrigation control	Jayaraman et al. (2016); Talavera et al. (2017); Marković et al. (2015)	Cost, labour and environmental risk reduction
	Big scale agricultural studies		Efficiency gains, labour and cost reduction
	Food value chain traceability	Tian(2017); Brewster et al. (2017); Marković et al. (2015)	Efficiency gains, social and environmental risk reduction
Meat and vegetables	Meat and vegetable condition monitoring and early warning systems across supply chain	Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Risk and cost reduction
	Meat and vegetables life		Efficiency gains

	prediction		
	Food-awareness for consumers		Social risk reduction
	Tracking livestock transportation		Efficiency gains and risk reduction
	Food value chain traceability	Tian(2017); Brewster et al. (2017); Talavera et al. (2017); Marković et al. (2015)	Efficiency gains, social and environmental risk reduction
	Environmental, soil and fertilization monitoring	Jayaraman et al. (2016); Granell et al. (2016); Talavera et al. (2017); Marković et al. (2015)	Cost, labour and environmental risk
	Irrigation control	Jayaraman et al. (2016); Talavera et al. (2017); Marković et al. (2015)	Cost, labour and environmental risk reduction
	Big scale agricultural studies		Efficiency gains, labour and cost reduction

As Table 1 shows, we also identified potential benefits for each potential application in terms of sustainable operations management. Although they can be classified in several ways, we choose those terms - labour reduction, risk reduction, social risk reduction, environmental risk reduction, cost reduction and efficiency gains - because they align with our proposed categorization of drivers and barriers for agrifood technological adoption.

In the next section we present a hypothetical farm context with operational use of IoT, plus some real-world IoT applications and devices in farming that are available or soon to be available for economical use.

Examples of IoT application in farming operations

A simple example to illustrate the potential operational benefit of using IoT in agrifood operations, specifically farming, can be described as such: a farmer that has a 100 hectare farm (1 km^2) with both milk and wheat, would have to spend part of the week (including weekends) personally monitoring his or her farm for diseases and harmful insects that might be hampering the farm productivity or even consumers safety. For this to be feasible, two options are normally available: 1. to use agrochemical products (insecticides and fungicides) pre-emptively, which is not sustainable (e.g. can be bad for the environment, for the farmer's health and is a cost) if not needed; or 2. to monitor in person (for integrated pest management, for instance). With IoT devices, the farm can be monitored automatically, with sensors not only evaluating potential risks for animals and plants in terms of pests (insects, fungus, virus, etc.), but also water quality, soil fertility, methane production from the cattle, among others. In other worlds, IoT enables a more complete analysis of the farm in a real-time fashion. The IoT-based system can then automatically identify specific parts of the wheat crop that needs agrichemical application for protection or that it is ready for harvesting, but also cattle that might have some problem or is ready for a specific process (insemination for instance). The farmer's machines can, with this information, know exactly where and when to act for such operations. After the production leave the farm, traceability elements can help consumers in all links of the supply chain to identify safety concerns regarding these products.

The hypothetical farm described above is already a reality. It is possible to find in the literature several projects being developed or already ready for commercial usage. For instance, Ray (2017)points out a number of IoT applications in agriculture, such as a system for soil monitoring, called CROPX's, TEMPUTECH's which is a wireless sensor for farm monitoring, CLAAS's smart devices, a platform for drone data named PRECISIONHAWK's, the Libelium network for tobacco crop quality by TEAMDEV, and JMB North America's connected cows. Guerra(2017) adds to these applications by identifying IoT uses in agriculture, such as Moocall and CattleWatch for monitoring animals, and Analog Devices Inc. for crop monitoring and precision agriculture, and self machinery and smart tractors and harvesters of both John Deere and Case IH.

With such a number of technological innovations available, theoretical considerations structuring technology transference and adoption would facilitate future TT approaches. The next section explores important concepts regarding key aspects of farmers' technology adoption that are taken into account in the model developed in this paper.

Farmers Technology Adoption

Investing in the adoption of a particular technology, whether it is a new device or a new agricultural practice, involves not only a decision on the financial input of it, but also the labour and the time that will be applied in its understanding and usage. There is vast literature on the subject of technological innovation, technology transference and technology adoption. Building upon this body of literature, we argue that IoT TT must take into account the potential elements influencing farmers' decision regarding technology adoption of IoT technologies.

The traditional economic theory regards decision making as rational and that it achieves the best option possible given the information the decision-maker has at the time(Taller, 2016; Mallard, 2017). However, humans are not completely rational, and new models of analysis have surfaced in the last few decades, most notably Behavioural Economics, that uses psychology insights for its studies (Mallard, 2017). In a similar fashion, studies in diffusion of technology and products consider differences between groups of decision-makers depending on a variety of factors, such as personality, motivation and culture. The seminal work of Rogers (2003), for example, classify groups of consumers as innovators, early adopters, early majority, late majority and laggards.

In our proposed model, we consider that elements influencing a farmer's decision can be positive (drivers) or negatives (barriers), depending on the vector (e.g. paying vs. receiving for a service) and on the intensity (e.g. more vs. less bureaucracy).We propose to classify such elements in the following categories: 'economic', 'socio-cultural', 'institutional' and 'operational'. The construction of said categories for the model is based on the similarities and differences among the influences shown in Table 2, and that were based on several authors: Asrat *et al.*(2010), Cunguara and Darnhofer (2011), Christensen *et al.*, (2011); Suri, (2011); Grabowski *et al.*(2014).As in the previous table, Table 2 does not try to encompass all the possible influencers for IoT TT in farming.

Table 2 – Elements influencing IoT Technology Transfer and Adoption

Category of elements	Influences
Economic	Expected cost reduction in production

	Expected net (profitability) gains
	Cost of the technology
	Availability of credit
	Perceived risk
	Subsidies
Socio-cultural	Maintaining family tradition
	Pride in being the most productive farmer in the region
	Land ownership
	Who is the main decision maker of the farm
	Decision-maker education (years studying)
	Past-experience with similar technology
	Neighbouring farms (technologies used, profit margins, etc.)
Institutional	Support infrastructure
	Supply constrains (availability of supply)
	Bureaucracy (paperwork, flexibility, etc.)
	Availability of extension programs
	Available labour in the region (if needed)
	Distance of the farm from urban areas
	Regulations (environmental, labour, etc.)
	Subsidies
	Being a part of a farmers' cooperative
Operational	Difficulty to operate the technology
	Perceived risk
	Limitations to field planning
	Labour input needed
	Electricity availability and stability
	Adaptability to the region
	Technology stability
	Support for the technology
	Size of the farm
	Type of production system

Besides the examples given in Table 2 in terms of potential drivers and barriers, several papers regarding IoT in farming consider that technical elements still need to be dealt with before a widespread operational use of such technology. This include, but are not limited to, platform definition, precise mathematical models, communication protocols and others (Karim *et al.*, 2017; Popovic *et al.*, 2017; Nikander *et al.*, 2017; Sorensen *et al.*, 2010; Sørensen *et al.*, 2011; Ferrández-Pastor *et al.*, 2016; Paraforos *et al.*, 2016). For a more complete understanding of IoT in agriculture in terms of development, uses and challenges, see Tzounis *et al.* (2017), Talavera *et al.* (2017) and Brewster *et al.* (2017).

Currently, there is no evidence that traditional TT methods and tools are different for IoT uptake in the agrifood sector. For this reason, the conceptual model presented in the next section identifies the most common tools and methods used in the agricultural sector: field days, agricultural fairs, model farms, courses, contracts and consulting (both private and by governmental extension agencies) (Janvry *et al.*, 2016; Chin, 2015; Comin and Mestieri, 2014), but are not limited by those cited.

Conceptual Model

Figure 1 shows the proposed conceptual model that integrates and facilitates analysis and assessment of IoT application and adoption, with improved operations sustainability as an implicit benefit element. As stated before, this paper focus on farming TT for IoT, although the agrifood supply chains have several other players (cooperative organisations, traders, logistics companies, supermarkets, etc.).

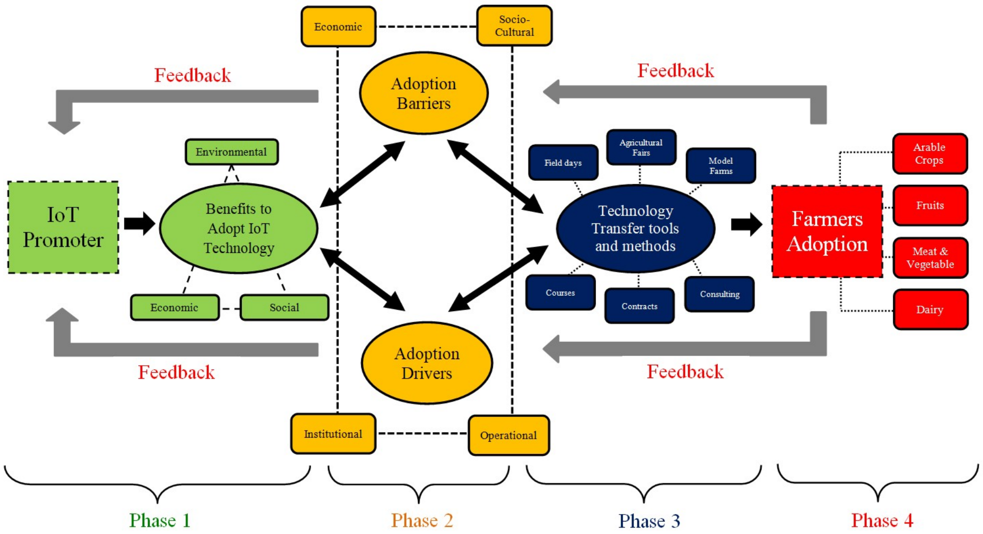

Figure 1 – Conceptual model of IoT technology transfer to farmers

The model takes into account a *technology-push* (Godin and Lane, 2013) view of innovation, starting at the IoT promoters, but the feedback that comes from the farmers, and pass through the adoption barriers and drivers - influencing them - are identified in order for the users of the model (IoT promoters, academics, policy makers, etc.) to take into account the view of farmers in empirical contexts when further developing the IoT devices for smart farming, and therefore also address the *demand-pull* (Godin and Lane, 2013) perspective of innovation, with an overall linear view of the topic.

Figure 1 shows the model with 4 consecutive stages:

1. Invention and/or development of the technology and the sustainability benefits that the usage of the technology can achieve;
2. Elements of influence that must be taken into account since they are important for farmers when making decisions. Those elements can be constrains or enablers;
3. Technology transfer tools and methods;
4. Farmers and their settings. Given that different agricultural domains have particular requirements, such as size of farms (e.g. grain farms tend to be bigger than milk farms), amount of regulations constraining the producer or how fast the product perishes after harvest.

By using the hypothetical farm described before as a basis, and considering other settings, we cannot conclude that everything (automatic monitoring, disease identification, cattle identification, self-driving machinery, traceability) will be useful or adopted by farmers in different contexts, such as a 1,000 hectare cattle farmer in Texas (USA), a 50 hectare tulip farmer in the Netherlands, or a 10 hectare maize farmer in central Africa. Even in the same country things might be very different, and Brazil shows this, when comparing smallholder farmers in the South and Northeast of the country (Buainain *et al.*, 2014). Even when considering the technical adaptation needed, both in terms of production system adaptations (e.g. diseases in that region, type of cattle) and technology (e.g. platform, energy requirements), other adaptations are needed. From legislation to educational level of the farmer, going through profit margins, risk acceptability, technological infrastructure, etc., IoT promoters must take all of this (Tables 1 and 2) into account when attempting TT of IoT for smart farming.

Conclusion

Although IoT has considerable benefits for farming operations, its adoption by farmers cannot be taken for granted. The paper provides a helpful theoretical basis that can support a practical tool to assess the potential of IoT adoption and transference across farming operations in the agrifood sector. The proposed conceptual framework takes into account operations management practices overlooked by studies in the area thus far.

If we consider the environmental constrains in food production, profit margins reduction, the increase in the age of farmers, and the reduction of available labour in agricultural regions even in developing countries – Brazil, one of the world biggest food producer/exporter currently faces these issues (Buainain *et al.*, 2014) – the adoption of IoT in agrifood has profound implications for all aspects of sustainability in food production and farm operations.

We believe that this model, or an evolution of it, can be further developed. In this sense we recommend the application of the conceptual model proposed in this paper as a basis to support further studies, preferably comparing its applicability in developed and developing countries. This would strengthen its reliability as a useful conceptual model to guide IoT technology transfer and/or its studies.

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