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The Internet-of-Things: Review and research directions

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ABSTRACT

This paper presents a review of the Internet-of-Things (IoT) through four conceptualizations: IoT as liquification and density of information of resources; IoT as digital materiality; IoT as assemblage or service system; and IoT as modules, transactions, and service. From the conceptualizations, we provide a definition of IoT and present its implications and impact on future research in Marketing that interfaces with information systems, design and innovation, data science and cybersecurity, as well as organizational studies and economics. By integrating the implications of IoT with extant literature, we then propose a set of priorities for future research in this area.

1. Introduction

Digitization is the conversion of analog information in any form such as text, images, sound or physical attributes to a digital format so that the information can be processed, stored, and transmitted through digital circuits, devices, and networks. In simple, pragmatic terms, digitizing information makes it easier to store, access, and share and process (Tilson, Lyytinen, & Sørensen, 2010; Yoo et al., 2010). As the world moves towards an era of Internet-of-Things, this paper argues that a technical process of converting previously static and unmovable information into a dynamic, transportable resource is creating disruption at a Schumpeterian level that is only just beginning. As a simple example, the cup on your desk holds information about its content, volume, color, and location. In an analog world, that information is only known to you as only you are able to see it. In a digital world, all information about that cup can potentially be 'seen' by anyone else. The 'leak' or 'liquification' of such information resources can create engagement and transactions not merely about the product function but also the state, action, and description of the product itself, together with the consumer interacting with it. We argue that such a technological ability that could render every physical object into a potential digital artefact will trigger limitless possibilities, both negative and positive, and could result in a fundamental transformation of institutions and other socio-technical structures.

Wireless sensor technologies now allow objects to provide information about their environment, context, and location (e.g. Alemdar & Ersoy, 2010; Ruiz-Garcia, Lunadei, Barreiro, & Robla, 2009); 'smart' technologies are touted as being able to allow everyday things to 'think and interact'; e-textiles or smart textiles are fabrics that enable digital components and electronics to be embedded in them (e.g., Stoppa & Chiolerio, 2014). Even old things could be potentially connected. Surfaces could be coated with conductive paint (e.g., Leong & Chung, 2006); electronic polymers now allow for smart glass as the surface for mirrors (Carpi & De Rossi, 2005; MacDiarmid, 2001); plastic electronics enable circuits to be produced at relatively low cost by printing electronic materials onto any surface, whether rigid or flexible (Kaltenbrunner et al., 2013).

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With nanotechnology and energy-scavenging technologies packing more processing power into less space, the potential to connect everything old and new for innovation and economic growth has sent the digital world into a creative tizzy. The term 'Internet-of-Things' (IoT) coined by Kevin Ashton, a technologist and pioneer in the Auto-ID world, has started to gain traction, and industry is beginning to wake up to the possibility of every object being part of the Internet, whatever the business proposition might be. The Internet and the physical world are about to experience an epic collision.

The objective of this paper is to first, review and present four conceptualizations of IoT. These conceptualizations are developed from the following theoretical constructs: liquification and density of information resources (Normann, 2001); digital materiality (Yoo, Boland Jr, Lyytinen, & Majchrzak, 2012); assemblage (Hoffman & Novak, 2015) and service systems (Ng, 2010), and modularity and transaction network (Baldwin, 2008). To be clear, by referring to Marketing, we mean Marketing as defined by the activity, the set of institutions, and the processes for "creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large" (AMA definition, Keefe, 2008). Our paper presents the conceptualizations and implications of IoT and draw the connections back to the principles of Marketing and the research conducted as we have known them for more than 50 years, arguing the impact an era of IoT would cause. In proposing the research priorities, we also integrate with literature from information systems, design and innovation, data science, cybersecurity, as well as organizational studies and strategy. By doing so, we hope to create a step change in expanding the knowledge base of Marketing and persuade researchers to actively engage in interdisciplinary IoT research.

2. Conceptualizations of the Internet-of-Things

The term 'Internet-of-Things (IoT)' was first introduced by Kevin Ashton to describe how IoT can be created by "adding radio-frequency identification and other sensors to everyday objects" (Ashton, 2009). Over time, the term has evolved into one that describes the IoT as a network of entities that are connected through any form of sensor, enabling these entities, which we term as *Internet-connected constituents*, to be located, identified, and even operated upon.

In the next section, we review four useful conceptualizations of IoT characteristics from various literature across the disciplines of strategy, operations management/manufacturing, systems theory, and information systems.

2.1. Internet-of-Things as liquification and density of information resources

One characteristic of the IoT is closely related to the notion of density of information resources. Density refers to "the best combination of resources [that] is mobilized for a particular situation — e.g. for a customer at a given time in a given place — independent of location, to create the optimal value/cost result" (Michel, Vargo, & Lusch, 2008; Normann, 2001). The density of information resources is crucial for achieving resource density. Previously, disparate information sets could be attained at different times and put together through organizational or consumption processes. The process of liquification and transportation of the information resource across space and time that is contextually relevant could enhance density of information resources (Michel et al., 2008; Normann, 2001). For Normann (2001), liquification refers to the separation of information from the physical objects, allowing the information to be easily moved about and re-manifested in many different ways (Michel et al., 2008). Liquification entails the transformation of a physical object's underlying information, description, or definition into information resources (Lusch & Nambisan, 2015). Liquification of the physical is able to generate a combination of disparate information resources and arrive at a relevant context almost instantly in some cases, achieving what is known as maximum density, where the best combination of resources is mobilized for a particular context (Lusch, Vargo, & Tanniru, 2010; Normann, 2001). This is achieved not only through liquification, but also through innovative information processing and knowledge engineering algorithms that can be executed on demand (e.g., Benaroch & Kauffman, 1999, 2000; Gruber, 1995). In the IoT, liquification further enhances the capacities of digitized objects. Intelligent sensors could provide precise real-time information about the involved devices and integrate with wireless sensors networks to better track and trace things in real time (Da Xu, He, & Li, 2014). In the IoT, each physical object has a rich set of data on current and historical information about that object's physical properties, origin, ownership, and sensory context, such as the temperature at which a milk carton is being stored in the fridge (Welbourne et al., 2009). For example, a toilet manufacturer, through embedding a sensor in its offerings, is able to 'liquefy' and liberate information about the state of the urine, which can serve as an information resource to be analyzed, stored, or shared on the person's wellbeing. This implies that the company is now able to create new software offerings in the health and wellbeing economy and indeed, derive revenues from the information resource that could complement or even replace the revenues received from selling toilets. With the IoT, and more liquification of information resources, such disruptions are set to increase. Liquification, and the subsequent processing and analyses of informational resources to support decisions and actions, is the fundamental driver of the 'smart' movement in the IoT.

2.2. Internet-of-Things as digital materiality

Closely related to the first conceptualization is the characteristic of the IoT as the digital materiality exhibited by physical objects (Yoo, Boland, Lyytinen, & Majchrzak, 2012). Physical materiality entails what a physical object can do. For example, clothes have physical materiality because they can be worn, but are difficult to be converted into a cup when you need one. Also, the consumption and experience of the physical carry social meanings. Digital materiality refers to what the software embedded in the physical object can do by manipulating the digital representation of the physical object (Yoo et al., 2012). For example, clothes