Internet of Things (IoT) - A Research Agenda for Information Systems

Article *in* Communications of the Association for Information Systems · May 2020

DOI: 10.17705/1CAIS.04725

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Communications of the Association for Information Systems

Accepted Manuscript

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Please cite this article as: Baiyere, Abayomi; Heikki, Topi; Venkatesh, Viswanath; Wyatt, John; Donnellan, Brain: Internet of Things (IoT) – A Research Agenda for Information Systems., *Communications of the Association for Information Systems* (forthcoming), In Press*.*

Communications of the Association for Information Systems

Research Paper ISSN: 1529-3181

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Abstract:

The Internet of Things (IoT) is emerging as an integrated set of digital innovations with the potential to unleash unprecedented opportunities as well as to create significant challenges from both technological and societal perspectives. The emergence of IoT heralds a new dimension of a digital era with impact and influence that are not yet fully clear. This signals the opening of valuable opportunities for scholarly inquiries, particularly for information systems (IS) scholars. We posit that, as the IS discipline sits at the intersection of technical, business, and social applications of IT, which are also the essential dimensions of the impact of IoT, IS scholars are well positioned to understand and contribute to advancing research on this new topic and associated phenomena. This paper outlines the distinctive attributes of IoT and their implications for existing traditions of IS research. It further highlights some illustrative research perspectives from which IoT can be studied by IS scholars. We highlight a research agenda for IS in two different ways: first, by suggesting four categories of implications on IS research: (1) introduction of the physio-digital continuum; (2) multi-level exploration of IS; (3) composite affordances; and (4) heterogeneity; and second, by introducing four thematic impact domains: (1) impact on organizations; (2) impact on technology; (3) impact on individuals; and (4) impact on society.

Keywords: Internet of Things, Research Agenda, Digital Innovations, Impact of IS.

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This manuscript underwent [editorial/peer] review. It was received xx/xx/20xx and was with the authors for XX months for XX revisions. [firstname lastname] served as Associate Editor.] **or** The Associate Editor chose to remain anonymous.]

1 Introduction

The concept of Internet of Things (IoT) has gained widespread use and attention among practitioners and in the trade press. Despite the growth of the industry, the focus on IoT and related phenomena has not, however, been quite as intensive in academic research. We believe that information systems (IS) as a discipline is in a unique position to contribute meaningfully to this emerging area of inquiry from a variety of perspectives (Baiyere, Venkatesh, Donnellan, Tabet, & Topi, 2016) . This will be particularly poignant given that the IS discipline operates at the intersection of social, business, and technical aspects of information technologies (ITs) (Baskerville, Baiyere, Gregor, Hevner, & Rossi, 2018; Benbasat & Zmud, 2003; King & Lyytinen, 2006). To this end, we present a research agenda on potential research directions in IoT.

There are different conceptualizations of IoT offered by scholars and practitioners (Atzori, Iera, & Morabito, 2010; Chui, Löffler, & Roberts, 2016; ITU, 2005; Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012). These definitions, with acknowledgement of their differences, have shared elements on which we base our concept of IoT in this paper. We define IoT as *a system of interconnections between digital technologies and physical objects that enable such (traditionally mundane) objects to exhibit computing properties and interact with one another with or without human intervention.* Digital technologies here could refer to software, sensors, electronics, actuators, digital identifiers, and network connectivity, among others. Physical objects refer to the traditional “things” in IoT, which could be any man-made or living objects with the potential to exhibit some digital capabilities such as sensing, data capturing, and/or communication. IoT captures the accelerated interconnection between the electronic domain and the physical domain—simply expressed as the expanding meeting point of *bits and atoms* (Ishii & Ullmer, 1997; Mitchell, 1996). With this overarching scale, IoT is arguably poised to touch (almost) every type of human endeavor, including energy, healthcare, manufacturing, agriculture, transportation, retail, education, and government (Kees, Oberländer, Röglinger, & Rosemann, 2015; Miorandi et al., 2012; Whitmore, Agarwal, & Da Xu, 2015). The range of societal, technological, and business opportunities/challenges that can be addressed with IoT is indeed broad (Shim et al., 2019). It is, therefore, essential that both scholars and practitioners pay attention to the impacts of IoT and the possibilities it creates.

IoT system implementations can include traditional objects that are augmented with built-on IoT capabilities, and/or objects that have built-in IoT capabilities, making them smart objects. In contrast to traditional objects, these enhanced devices pass digital interactions and feedback/data throughout a process and between process infrastructure, user feedback and each other. Traditional objects, however, are only able to pass manual interactions and feedback (see Figure 1). As a user pursues accomplishing an end goal, they are following a process enabled by traditional information systems. With IoT systems, information can be passed between the user, objects, and processes to enable the desired goal.

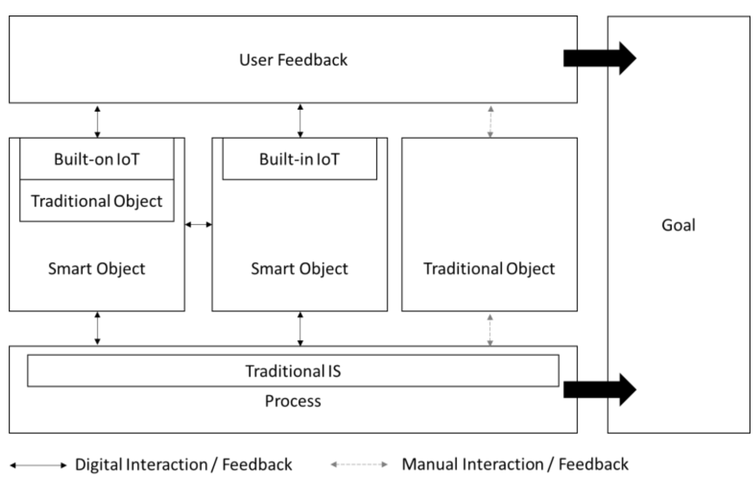

Figure 1: Illustrative representation of an IoT system showing relationship between smart objects, traditional objects, and traditional IS

Despite the scale of the anticipated impacts of IoT, its full potential and utility are understudied and yet to be fully established. Among other research possibilities, this opens up an opportunity for the IS community to play a pivotal role in identifying, outlining and stimulating new and unique application areas for IoT as well as mapping out the associated implications of IoT for both business and society. In addition, IoT presents critical ethical, legal, and policy dilemmas. The possibilities and scope for abuse and misuse arise, particularly from the breadth and depth of the reach of IoT within individual lives, business activities, and societal policies (Dlodlo, Foko, Mvelase, & Mathaba, 2012; Sicari, Rizzardi, Grieco, & Coen-Porisini, 2015; Whitmore et al., 2015; Da Xu, He, & Li, 2014; Zuboff, 2015, 2019). To highlight a few of these concerns, some of the key areas worthy of scholarly attention include security issues and current technological limitations (Qin et al., 2016) as well as surveillance capitalism (Zuboff, 2015, 2019). As a practical example, we can identify such concerns in cases such as the hacking of a 2014 Jeep Cherokee by security researchers in which they were able to take control of the vehicle when it was in motion (Greenberg, 2015; Pogue, 2015; Von Roessing, 2016). Another example is the exploitation of loopholes through which researchers demonstrated that they could, among other things, hack into a Nest Learning Thermostat of a home, spy on its owner, take advantage of other devices on the network, and steal wireless network credentials (Hernandez, Arias, Buentello, & Jin, 2014). The vulnerability and associated exploitation of these devices is of primary concern due to their implications to the safety of both the users of the systems and the data flowing through them. These issues provide the motivation to stretch the current knowledge in search of ways to overcome these challenges and limit the negative consequences of IoT while realizing its positive potential (Shim et al., 2019). Both technical and social research engagements are likely to contribute to the solutions of these highlighted issues.

From a historical perspective, it can readily be seen that from the advent of telephones and automobiles of the previous century to computers and smartphones in recent times, technological advances typically have both positive and negative consequences. Each successful technological wave can be associated with different changes that impact individuals, organizations and the society as a whole. It is possible that IoT will be deemed to be one of the successful waves (Li & Xu, 2015). However, it is yet to be determined if IoT as a phenomenon is a product of technology hype or an emerging technological wave that carries noteworthy significance. A plethora of questions and possible inquiry points abound. This paper explores this question from practical and theoretical perspectives and proposes elements of a research agenda for scholarship in this direction for the IS discipline.

As we reflected on IoT, its potential, and its implications for IS research, we were struck by how the genesis of IoT can be traced back to several constructs that have been actively studied in prior IS research. For example, some IS concepts relevant to IoT include ubiquitous computing, web of things, industrial Internet, physical Internet, smart cities, pervasive Internet, connected environments, situated computing, wireless sensor networks, among several others (Forman, Goldfarb, & Greenstein, 2005; Gholami, Watson, Molla, Hasan, & Bjørn-Andersen, 2016; Kohli & Grover, 2008; Lyytinen & Yoo, 2002b, 2002a; March, Hevner, & Ram, 2000; McCullough, 2004; Wolcott, Press, McHenry, Goodman, & Foster, 2001; Yoo, Henfridsson, & Lyytinen, 2010).

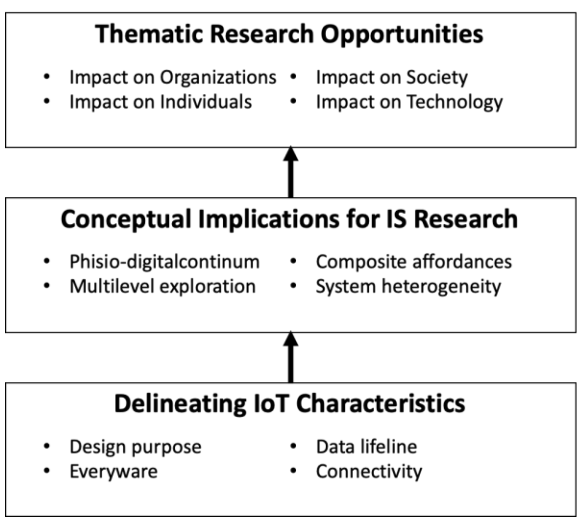

Figure 2. Towards an IoT research agenda in IS

We first unpack the delineating characteristics of IoT that differentiate it from regular objects, IT objects, and smart objects. These characteristics are *design purpose, everyware, data lifeline* and *connectivity*. We then provide a justification for why IoT holds potential as a relevant and important topic for the IS discipline to study. This is examined by outlining the potential of IoT as well as the unresolved challenges that are opportunities for scholarly inquiry from two different perspectives. First, we use these characterizations of IoT as a locus for presenting conceptual implications to conduct and think about future research around IoT in the IS discipline. Second, we outline an illustrative research agenda around three impact domains. The structure is outlined in Figure 2.

2 Scholarship Opportunities: IoT Potential and Challenges

An unfolding reality is that IoT technologies and solutions are here and projected to keep growing. By this year, it is expected that there will be seven billion people and businesses connected to the Internet compared to more than 35 billion connected things (Lopez, 2016), including 250 million cars online (Velosa, Hines, LeHong, Perkins, & Satish, 2014), and even connected animals (Tratz-Ryan, Jones, Ingelbrecht, & Escherich, 2014). All this information will create hundreds of Zettabytes of data (Turner, Gantz, Reinsel, & Minton, 2014) that could comprise a $2 trillion economic value-add (Burton, Burke, & Blosch, 2016). Although this presents massive opportunities, there are significant technical, policy, and social challenges that will need to be addressed. Further, IoT is often talked about as the next industrial revolution that is fast approaching. However, we already live in a world where the number of connected devices has exceeded the number of people on the planet. Far beyond the smart thermostat in our homes, IoT applications are spreading across industries, connecting the physical world to the digital realm. Applications of IoT save lives with wearable medical devices that monitor patients' vital metrics. They improve the quality of the air we breathe by managing emissions from factories and cars. Supply chains are now monitored real-time from cradle to grave. These characteristics and outcomes of IoT open up a plethora of research avenues to understand the social, business, and technical components of IoT research.

The fact that technical developments have made it possible to make both small and large physical objects smarter, capable of communicating with their environment regarding their status and behavior, and able to send and receive control instructions, is alone insufficient to create an interesting area of research. Many applications of IoT require having seamless interconnectivity and integration of physical and digital realms, and ability to process vast quantities of heterogeneous data created at very rapid speeds. This is still, however, not enough to make a case for a new research area. We need to go beyond the practical potential to an engagement that generates insights of theoretical and practical value. When considering a research agenda for IoT in IS, it is essential to first think about a set of fundamental assumptions regarding the relationship between the IS discipline and the target of interest here—IoT. This is particularly important given the multidimensional nature of IoT as a phenomenon.

First, over the relatively short history of the IS discipline, we, as IS scholars, have positioned IS as a multi-faceted discipline looking at the intersection of the social, business and technical aspects of IT. IS journals have published many good classifications of IS as a field of research from multiple perspectives. To use a couple of recent examples, Abbasi, Sarker, and Chiang (2016) specified three IS research traditions: behavior, design, and economics of IS. Sidorova, Evangelopoulos, Valacich, and Ramakrishnan (2008) identified five core IS research areas: IT and organizations, IS development, IT and individuals, IT and markets, and IT and groups (essentially providing evidence regarding the importance of the association between technology and four different levels of human activity in IS research). Using just these two frameworks as examples, these types of efforts are important in any systematic process for exploring opportunities for scholarly work related to a new phenomenon. How does work on IoT fit with the social, business, and technical IS research traditions? To what extent is IoT as a technology relevant to the levels of analysis identified by Sidorova et al. (2008)—individuals, groups, organizations, and markets/societies?

Second, the focus of the IS discipline is more on organizational and individual implications, transformation of human activity, use, and generation of value from IT than just on the IT itself. The IS discipline emphasizes questions that address the impact and transformational power of IT on goal-driven, purposeful human activity at individual, group, organizational, or societal levels. Data, information, systems, and/or technology alone have little value if we do not make an attempt to understand them in the context of the purpose to which they are applied. This contextual understanding should be an integral part of research efforts related to IoT.

Third, it is worth recognizing that there are many essential questions related to the development of IoT technologies that are unlikely to be the key strength of our discipline. We should strive to find our own distinctive perspectives and forms of scholarly contributions related to IoT rather than trying to focus on the types of questions and challenges that do not fit the scholarly agendas of our discipline. We should explicitly acknowledge that there are areas outside our focus and that we will rely on work by others in many dimensions of work related to IoT, including key elements of the technological foundation. We should be prepared to expand our horizon as we embrace the new frontiers of scholarly inquiries that IoT provides us but acknowledge the areas within IoT where it is essential that we collaborate with others.

Fourth, we should not ignore the links between IoT and other currently relevant IS phenomena. The IS community is building bodies of work on, for example, big data (Abbasi et al., 2016), digital infrastructure (Tilson, Lyytinen, & Sørensen, 2010), digital innovation (Yoo et al., 2010)), and healthcare (Fichman, Kohli, & Krishnan, 2011), among many others (Baiyere et al., 2016). We believe that a large proportion of our prior accumulation of knowledge remain highly relevant for scholarly work on IoT. Although there is value in drawing on our foundational theories, we should avoid falling into the trap of wielding our prior theories as hammers in which IoT is perceived as another nail. Nonetheless, we should consider drawing from our current research streams as possible models for organizing and understanding IoT as a phenomenon.

3 Delineating Characteristics of IoT

In general, using IoT as an opportunity to move the boundaries of future IS research beyond the discipline's current boundaries does not suggest that IoT systems are totally different from other IT systems. On the contrary, IoT provides a foundation for new types of IS that draw on prior knowledge and principles of both IS and IT. Rather than debating the distinctiveness of IoT as a new field of inquiry, we consider it more relevant and useful to talk about how IoT encourages us to expand the horizon of IS research. In light of this, we highlight four delineating characteristics of IoT that help us articulate how IoT systems are distinguishable from other systems. In doing this, we shift the focus of discussion away from the static question of *what* is IoT to a dynamic question *when* is IoT? That is, what characteristics need to be present at a particular point in time and what capabilities the interacting elements need to bring to the whole for the entire system to be considered IoT and the elements to be considered IoT components?

We draw the premise of our positioning from the logic of Star and Ruhleder's (1996) "when is an infrastructure" and Engeström's (1990) "when is a tool" ideology. We consider these perspectives relevant in unpacking IoT rather than an engagement with the "what is IoT" question. Our conceptualization of IoT is not as a thing with preset attributes frozen in time; rather, IoT represents a system in practice, an ensemble of things in a context and in connection to some particular activity. This view suggests that an object can exist as a component of an IoT system or exist independent of IoT. The "when is IoT" conceptualization explicitly recognizes the importance of component interaction for the existence of IoT—without this interaction, the components with IoT potential still are not IoT even though they happened to be physically present. This is in contrast with prior views that consider IoT to be a specific entity that is defined by its perpetual existence and IoT attributes (Atzori et al., 2010; Chui et al., 2016; Iera, Floerkemeier, Mitsugi, & Morabito, 2010; Miorandi et al., 2012). Although this view provides valuable foundations for understanding IoT as a theory, such conceptions assume that IoT is a given and takes for granted the connectivity essence of IoT that makes it amenable to a system perspective rather than as an isolated device. Further, this static conception of IoT puts our thinking in a straitjacket in which an IoT object *is* part of an IoT system with little consideration that an object *can become* or cease to be a part of an IoT system. It is this static notion that concerns us and informs our shift of focus to the question of *when*—rather than *what*—is IoT. Please note that "when is IoT?" is a shortcut for "when (or under which conditions) does a set of elements with IoT potential actually form an interacting collection of capabilities that can be considered to be IoT?"

Before we articulate the main ways in which we see IoT as expanding the boundaries of IS research, we need to address some terminological nuances. *IoT* as a whole refers to the entire network of interconnected nodes, whereas *IoT technologies* refer to the technical capabilities that enable the construction and functioning of IoT objects. *IoT objects* can be regarded as unitary elements or "things" within an IoT context. *IoT systems*, in turn, are subsystems of IoT as a whole designed for a specific community of practices—individual/home settings, organization/group of organizations or society—with a specific purpose. With this background, we turn next to presenting four distinctive characteristics of IoT systems/objects that can provide us with a granularity and lens for establishing a distinction between these and other systems/objects. These are *design purpose, everyware, data lifeline,* and *connectivity* (see Table 1). The first two provide a delineation based on the "thingness" of IoT in contrast to IS, whereas the last two provide a delineation between the "internetness" of IoT in contrast to ordinary things. It should, however, be noted that these characteristics are not presented as comprehensive representation of *what* is IoT. Rather, we present these characteristics as parameters for delineating *when* an object is a regular object, an IoT object, or an IS object.

Table 1. Delineating IoT from related concepts

Delineating Characteristic	Regular object	IS object	IoT object
Design Purpose: Captures the underlying purpose of an object with regard to whether the primary objective of the object is computing, non-computing or it has been repurposed to combine the purpose and properties of both. Useful for delineating between all three class of objects.	Key design purpose is non-computing. Example: A chair's design purpose is primarily for sitting.	Key design purpose is computing. Example: A computer's design purpose is for data processing and computing	A combination of the design purpose of regular and IS objects that effectively enables the repurposing of the primary design purpose of the objects. Example: The key design purpose of a smart watch is different from (and much broader than) that of a regular watch or the computing capabilities enabling a watch to become an IoT object.
Everyware: Reflects the expansion of what qualifies as a hardware in the computing sense from physical computing technologies to any regular object. Useful for delineating IS objects and IoT objects	Objects with a potential to be a conduit for computing but that is yet to be exploited. Example: A traditional object (e.g., chair) affords the possibility to be a conduit for computing.	Hardware are primarily dedicated physical computing objects that have clear computing functionalities. Example: Printers, monitors, routers, etc.	Extends the concept of hardware from dedicated devices to literally any object with computing and digital communication functionalities. Example: A smart fridge, a smart shoe, a smart spoon, etc.
Data Lifeline: Positions data as a fundamental necessity for any object to qualify for consideration as an IoT object. Useful as a characteristic for eliminating regular objects from the trio.	Devoid of data in fulfilling its design purpose. Example: A chair does not need data to function.	Dependent on data in fulfilling its design purpose. Example: Computers, routers, specialized storage devices, etc.	Dependent on data created and received by the object when fulfilling its design purpose. Example: Smart devices in general.
Connectivity: Emphasizes the need for objects to exist in connection to other objects in other to be part of an IoT system. Useful for distinguishing regular objects, IS objects or (singular smart/ potential) IoT objects from IoT objects in an IoT system.	Due to the limitation of data lifeline and the digital nature of most regular objects, they lack the capacity to digitally connect and communicate with other objects. Example: Dining table and chair.	An IS object can possess the propensity to connect to other objects and communicate. This is a shared characteristic between an IS object and an IoT object that distinguishes them form regular objects. Example. Computers on a LAN network.	Besides possessing the other characteristics an IoT object needs to be connected to other objects and be able to synchronously or asynchronously communicate beyond its own silo when fulfilling its design purpose. Example: A personal assistant like Siri, Alexa; a robotic arm in a connected factory, etc.

3.1 The "Thingness" delineation

3.1.1 Design purpose

Design purpose as a *thingness* characteristic of delineating IoT refers to the innate purpose of an object with regard to whether the primary objective of the object is computing, non-computing or it has been repurposed to combine the purpose and properties of both. A typical characteristic of IoT objects is the presence of regular objects having digital properties (Wiberg, 2018). Traditionally, there lies an intrinsic and distinctive purpose in the design of an object. For example, a chair has historically been designed with the purpose of serving the users' unmet need to sit. With IoT, a chair can be digitized and repurposed for a wider range of options than what was traditionally considered its initial purpose. Understanding the underlying design purpose of an object serves as a qualifier for distinguishing if an object possessing digital properties is an IS object or an IoT object. Thus, design purpose distinguishes existing IS artifacts and IoT objects by placing the focus of distinction on the primary purpose for which an object and/or its components are designed. For example, traditional infrastructure components of an IS, such as a computer, a router, and a printer, all have been designed with computing capabilities as their underlying purpose. These items have been designed to serve primarily as computing artifacts. IoT objects, in contrast, are objects that integrate non-computing design purposes with computing or digital properties or IoT devices that enable non-computing design purposes. To distinguish whether or not an object is part of a system with IoT properties, it is useful to first separate the original (design) purpose of the object from the digital properties that it possesses or vice versa. With this distinction, we can achieve a clearer positioning of the components for our theorizing about traditional IS artifacts versus IoT objects.

The relevance of the design purpose as a distinguishing characteristic of IoT is that it compels us to take a step back in evaluating components of an IoT system before enveloping them with prior assumptions with which we have traditionally considered IT artifacts. For example, a spoon acting as a thermometer interfacing with a health kit that then communicates with a fridge to decide the content of a person's grocery list could be arguably dismissed as an IS setup of devices with embedded software and communication protocols. Although such a view is somewhat accurate, it nonetheless clouds the distinctiveness of the "things" in this scenario (Barnaghi, Wang, Henson, & Taylor, 2012) with a generalist imposition of a familiar IS conception. Such conceptions logically come along with preconceived notions and assumptions that limit us from exploring the interplay between the physical and the digital. We contend that IoT requires a shift of the field from a dominant focus on the digital to a view that considers and embraces the interaction between these two domains. It is in such a shift in perspectives that we can open up new theoretical frontiers from IoT as opposed to force-fitting it into prior thinking models.

3.1.2 Everyware

Everyware reflects the expansion of what qualifies as hardware in the computing sense from physical computing technologies to any regular object. This stems from the fact that another characteristic of IoT is that it enlarges the scope of hardware in IS to "everyware" (Greenfield, 2006). The notion of everyware (using a term coined by Greenfield (2006)) captures the propensity for literally any object to become a component of an IoT system (Wiberg, 2018). In IS research, we generally consider IT systems as having at least three key components—that is, they are typically composed of a tripartite of hardware + software + data (Patterson & Hennessy, 2013; Pitt, Watson, & Kavan, 1995). In an IoT system, however, the view of what embodies an IT system is expanded. This change requires moving from the hardware perspective to the "everyware" perspective. Hence, although we have typically considered IT systems to include hardware + software + data, IoT is composed of everyware + software + data. Software and data remain largely with similar identity and composition in IoT as in IT. However, the hardware concept is expanded in the IoT context to include not just IT hardware but any and every object that can be made to possess a digital identity. This expansion can be considered to be what is captured by the "things" concept in IoT (see our definition of IoT). In essence, prior mundane objects that do not qualify to be hardware in a traditional IT sense can effectively be converted into everyware in the IoT context with appropriate IoT technologies. The distinctiveness of this characteristic comes into force when evaluating if a system is an IoT system or a traditional IT system.

This characteristic can play an important role in future theorizing about IoT systems as it calls attention to the physical nature and properties of the object beyond its encapsulation of an IoT functionality. This pushes us to expand our lexicon within IS to account for this changing conception of what a hardware is in an IoT context. Without such a distinction, there is a tendency that all IoT objects and sundry would be considered hardware that, we argue, would hinder us from uncovering the theoretical potential of engaging with the physical affordance and exposition that the everyware concept offers beyond prior perceptions of hardware. In summary, the value of this distinction enables us to embrace the "thingness" of IoT objects rather than bracketing them within our prior logic and assumptions about hardware in IS systems. The characteristic also points to the similarity in terms of the presence of software and data as intrinsic components of an IoT system that draws parallels with prior conceptions of systems in IS.

3.2 The "Internetness" delineation

3.2.1 Data lifeline

Data lifeline represents the necessary condition of the presence of data as a fundamental requirement for any object to qualify for consideration as an IoT object. Whereas the first two characteristics have emphasized the distinction between objects/artifacts in IoT versus IT, data lifeline focuses on differentiating between IoT objects and regular objects. Considering the physico-digital nature of IoT, there is value in going beyond the distinction between IT and IoT to identifying how IoT objects are uniquely distinct from other regular objects. The characteristic of everyware leaves us with an open question—when is a specific object a part of the IoT instead of being just another regular object? Essentially, where is the boundary or point at which a regular object becomes potentially recognizable as an IoT object? The characteristic of data lifeline provides us one step in answering these questions. Data lifeline indicates that an object needs to have a data capability (e.g., collection or creation) in some form or another to qualify as a potential IoT artifact. The key premise of this characteristic is that the construct of IoT ceases to exist in the absence of data. If an object loses its data lifeline— its digital quotient—it may still have its physical properties to fulfill its primary design purpose but no longer holds claim to being an IoT object. Data lifeline is, however, only a necessary but not sufficient characteristic to determine an object's classification as a component of an IoT system versus one that is not—hence, the value of the connectivity characteristic.

The data lifeline characteristic finds relevance in its capacity to delineate between whether an object potentially qualifies to be considered as an IoT object or a regular object. Data lifeline provides a simple metric for eliminating many regular objects from consideration as IoT objects, which provides practical utility in empirical considerations about IoT studies. This delineation is also important when considering instances where the presence of a sensor in an isolated object leads to consideration of such an object as an IoT object. For example, a revolving/sliding door or automatic light switch that automatically swings into action on detecting movement is a regular object. Such isolated interaction could potentially be captured as a set of data points or combined with other data functionalities toward making this an IoT object. However, the hardwired sensor logic in itself does not capture the notion of a data lifeline that gives it the digital quotient to be an IoT object. Although the data lifeline is an important precursor to being an IoT object, it leaves open the possibility that an object that fulfills this characteristic may also be an IS artifact. Hence, this is a characteristic that needs to be considered in conjunction with another characteristic rather than in isolation.

3.2.2 Connectivity

Connectivity captures the need for objects to exist in connection to other objects in other to be part of an IoT system. This is another essential delineating characteristic of IoT. Connectivity implies that the object is not a standalone object (Mitchell, 2004) but one that has the capacity to convey its data to other objects; it is related to data lifeline in that neither is sufficient alone, but data and the mechanism to transfer data are clearly independent dimensions. Connectivity can be used to differentiate IoT from smart objects. By definition, IoT implies an interconnection of objects and does not apply to objects functioning in isolation. This resonates with Mitchell's (2004) rephrasing of Descartes from *"I think, therefore I am"* to *"I link, therefore I am"*. An object may function alone and have intelligent properties, but it would still be better classified as a smart object (say, a standalone robotic vacuum cleaner) than a part of the IoT, if it is not connected with other objects. It is also important to highlight that an artifact is not an IoT object on its own but only a component of an overarching IoT system and IoT as a whole. Hence, an object becomes part of an IoT system only when it has some form of data connection to the system and can communicate the data either synchronously or asynchronously between different objects in the system.

The connectivity characteristic helps us avoid automatically considering every object that has a sensor or handles data in some way as an IoT object. Further, the connectivity characteristic brings the notion of system into the IoT domain. This suggests a relational and network perspective for considering IoT. Such a perspective further brings the IoT concept to a granular level in which an IoT context can be studied as a collection of IoT objects rather than a vaguely bounded notion of IoT. In addition, this characteristic enables us to avoid mixing apples and oranges in our theorizing about smart objects and IoT but gives us a lens for conceptually unpacking both concepts as distinct yet related theoretical and empirical domains.

4 Foundational Implications for Research on Information Systems

Building on the process of identifying the delineating underlying characteristics of IoT discussed in Section 3, we outline here four areas within which the introduction of IoT leads to essential foundational implications for IS research. More specifically, these implications are not only pertinent as we engage with scholarship on the topic of IoT, but they also encourage us to reconsider several broadly held assumptions underlying information systems a whole. The implications we will discuss below at a more detailed level are the need to: 1) move our focus from purely digital to physico-digital characteristics of systems and system components; 2) strengthen the multilevel nature of IS research; 3) consider the emergent composite affordances created by intertwined physical and digital affordances; and 4) recognize heterogeneity that the presence of IoT characteristics introduces to any system. We believe it is essential that the IS research community specifically considers the impact of these four types of changes on systems that include IoT capabilities.

4.1 Physico-Digital Continuum

The IS discipline has typically focused on various facets of being digital, digitization, and digital transformation (Fürstenau, Baiyere, & Kliewer, 2019; Tilson et al., 2010; Wessel, Baiyere, Ologeanu-Taddei, Cha, & Jensen, in press; Yoo et al., 2010). However, IoT research has the potential to shift the locus of IS research from a primary focus on digital aspects to one that considers and pays attention to the digital, the physical, and particularly the interaction between the two. IoT, by definition, requires the amalgamation of the physical and digital domains. With IoT, these two are no longer viewed as disparate entities (Wiberg, 2018) but as an intertwined ensemble (based on the everyware delineating characteristic discussed earlier). This is perhaps an anomaly to the call for an ontological reversal with the notion of "digital first" (Baskerville, Meyers, & Yoo, in press). In the context of IoT, we may be witnessing an "ontological integration" rather than a reversal and a notion of "digital too" rather than digital first. Given that many IS theories are developed to cater solely to the digital domain, IoT opens up possibilities to a new frontier for re-evaluating IS assumptions and in advancing novel IS theories that consider the interplay between the digital and the physical and not necessarily an ordering of one before the other.

This raises the question of how we conceptualize IT artifacts in our theorizing in the IoT context where the digital and physical elements are naturally intertwined. The implication of this physico-digital nature of IoT to IS scholarship includes a need to reflect on both the scope and definition of the central IT artifact that our studies revolve around. The change heralded by IoT in this regard is not simply a change in technology but a fundamental expansion of our domain of scholarship from purely digital to areas where digital and physical act together. Although it is arguably possible to disentangle the digital as a phenomenon from the physical in IoT studies, we argue that such an approach denies us the richness of insight that can be unearthed by considering the intertwining between the physical and the digital (Wiberg, 2018). The projections around the growth of IoT suggests that the idea of what is considered IT today may be experiencing a shift where IT gradually becomes synonymous with IoT in the future: it will be so commonplace for the digital and the physical be intertwined that it will not anymore be necessary to label it separately. It is thus in our interest as a community to engage in scholarship that expands our domain from the digital to the physico-digital. We perceive that such a transition is likely to bring to fore a need to rethink what an artifact means in an IS study before we set out to desperately seek out the IT artifact, as recommended by prior research (Orlikowski & Iacono, 2001).

This composite affordance further has implications for IS, as it blurs how we conceptualize the boundaries of the core phenomena of focus in the IS discipline. Prior to IoT, the process of outlining the boundary of a system was straightforward with a clear delimitation of the IS artifact in focus, which can be readily identifiable with the tripartite of hardware, software, and data. With such a conception, other items within IS research could be regarded as contexts, actors or non-IS artifacts. With IoT, this conception requires some rethinking in order to understand how to accommodate the shift in the boundary of the focus of study in an IoT context. This is particularly pertinent as this may reveal limitations in our prior theories or sharpen the applicability of extant theories to illuminate our understanding across different conceptualization of the boundary of our object of focus in IS studies. This may lead to a redefinition of the scope of the discipline, as we seek to further legitimize and strengthen our position and identity as an academic discipline (Benbasat & Zmud, 2003; King & Lyytinen, 2006).

Historically, with the focus on digital elements in IS research, we have barely considered the materiality of the artifacts in our earlier core streams of research. Perhaps the closest genres of IS research that place some emphasis on the materiality of the artifact are the design science paradigm and the WITS community. This digital inclination over materiality has historically made sense as the field focused more on the software and data applications and possibilities of the IT artifact within social and managerial contexts. With this line of thinking, we considered the technical or hardware aspects of the artifact to be more related to the engineering and hard sciences. However, with IoT, the materiality, which draws on the physical properties of the artifact, becomes an important component of making sense of IoT studies. We can no longer downplay the importance and relevance of the constituent materiality of the systems we study as the physico-digital combination provides a new perspective for considering a system of study.

4.2 Multilevel Exploration of IS

IoT provides an avenue to conduct IS research that cuts across multiple levels of enquiry. Research in the IS discipline has traditionally been defined in terms of social, organizational, and managerial relations that has placed less emphasis, and even so only recently, on the individual outside the organizational context, such as personal use (Baskerville, 2011). With the notion of things in IoT and its extension to everyday objects that individuals interact with regularly—either in work or life contexts—IoT provides us with unprecedented opportunities to study IS phenomena at finer levels of detail from the individual level to higher levels of analysis and abstraction. Connectivity as a delineating characteristic leading to potentially highly intensive communication between IoT objects forces us to pay attention to both behaviors of individual components and the outcomes of the communication between the system elements. Even within an organizational research setting, the level of granularity can be zoomed in to pick minute details of individual-level phenomena within an IoT context. As an example, in an industrial Internet of things (IIoT) context, the implementation of IIoT systems could provide a holistic overview of a manufacturing workshop while, at the same time, such a system can provide deeper insights into the practices of individuals as well as their interaction approach with the machines on the workshop floor. Similarly, studies around smart cities can provide a nexus for combining individual-level data and city data as an empirical basis for exploring the relationship between the macro and micro events in a societal context (Bassoli, Brewer, Dourish, Martin, & Mainwaring, 2007; McCullough, 2004; Mitchell, 1996).

Although traditional IS theories address a variety of phenomena in organizational contexts quite well, one might wonder about their applicability to non-organizational settings. IoT penetrates every aspect of life, including work and personal spaces (McCullough, 2004; Mitchell, 1996), which opens up new implications for how we think about IS across different levels and the extent to which prior theories apply in such multilevel contexts, particularly the undertheorized individual level (Vodanovich, Sundaram, & Myers, 2010). As Baskerville (2011, p. 251) notes, the emergence of individual-level issues in the study of IoT devices as these devices become everyday objects is happening "just beneath the noses of information systems (IS) researchers". An increased focus on IoT may help us broaden our perspective from the centricity of the organization as the dominant research context, which can be traced to the days when the IS used by individuals were trivial, especially by today's standards, and basic paper-based systems or simple systems.

4.3 Composite Affordance

Because IoT objects are essentially a bridging of two disparate domains, that is, the physical and the digital (Stankovic, 2014), the emergent affordance of the IoT artifact is the combined affordance of the two domains plus the many other opportunities opened up due to the interconnection with other objects. With composite affordance, the affordance of IoT emerges from the two constituent domains, physical and digital, with significantly different capabilities that, when combined, produce affordances different from the individual components. The capabilities of everyware are much more than either software or hardware components alone. An IoT system cannot be considered with a singular focus on the affordance of the digital or physical alone, but both need to be considered along with the affordance that is enabled by their interaction (Leonardi, 2011), based on the design purpose and connectivity delineating characteristics from Section 3. In essence, the point of departure of IoT from the focus of prior IS research lies in the affordances that IoT brings from the physical domain, moving us beyond what would be possible by studying the affordance of the digital domain alone.

The implication of this for our theorizing is in how we consider the possibilities and limitations of an IS artifact. For example, it would be atypical to have considered the affordance of an IS artifact to include "seating" in a traditional IS study. However, in the context of IoT in which the IoT object or artifact of study is a chair, the affordance of "seating" becomes a logical capability that is afforded by the IoT artifact in conjunction with other digital affordances that it inherits from the interaction between its physical and digital properties as an IoT object (e.g., a change of color if the weight on or temperature of the chair exceeds its specified limit). These composite affordances that are opened up by IoT have the potential to influence our theorizing to not only hold relevance for the digital domain, but also hold relevance to the physical domain (Leonardi, Nardi & Kallinikos, 2012; Norman, 1999, 2008). At the same time, the infusion of composite affordance into our theorizing could reveal areas where our generalized assumptions may require refining and recalibration to take into account these new forms of affordances.

Another implication of the composite affordance is its potential to put the spotlight on the role of IS as a discipline that is located at the intersection of social, business, and technical scholarship (Baiyere, Hevner, Gregor, Rossi, & Baskerville, 2015; Baskerville et al., 2018; Benbasat & Zmud, 2003; King & Lyytinen, 2006), as we will discuss in the next section. This is because the process of unwrapping the composite affordance of an IoT would require studies that leap beyond the silo approach that characterizes most of IS research to an approach where IoT studies draw upon multiple perspectives. In the IoT era, IS scholarship is uniquely positioned to leverage its peculiar location at the intersection of the social, business, and technical research. This is even more so the case because IoT is bringing different worlds together: the technical world and social world; the Internet age and industrial age; and the digital world and physical world. There is a disciplinary void to be filled, as we strive to understand these distinct perspectives and build bridges to connect and leverage the differences. The IS discipline is in an excellent position to play an important role in filling this gap (Goles, Hawk & Kaiser, 2008). In this sense, research studies on IoT could benefit from leveraging the technical characteristics of IoT and probing deeper into the underlying mechanisms through which IoT innovations enact themselves within our socio-technical structures. These studies also have the potential to reveal theoretical insights relevant to IS research on the behavioral, managerial, and design implications of their application.

4.4 Heterogeneity

Given its broad reach and complexity based on intensive connectivity, the presence of IoT in a system context naturally introduces multiple types of heterogeneity into the system (Barnaghi et al., 2012). For example, let us consider an IoT system that uses data from various types of traffic sensors and integrates it with mapping capabilities to provide traffic guidance. This example highlights the way in which IoT capabilities introduce heterogeneity of goals into the system. The goals an individual has for this type of a system are likely to be very different from those of a community (city or town) or society: when an individual might want to minimize his or her travel time, the community might want to minimize traffic congestion and the society reduce the level of CO_2 emissions. Not only are these goals different, but also are conflicting, requiring multilevel conversations among stakeholders to determine the priorities between potential system outcomes. Da Xu et al. (2014) have identified the same need to achieve a balance of competing goals in the context of IIoT.

From another perspective, many IoT systems bring together a broad variety of devices that are quite different, except for the data they collect and the protocols at various levels that they use for communication (Barnaghi et al., 2012) and that make it possible for these heterogeneous components to interact. The disparate devices create a wide range of interactions that contribute toward the overall system experience. For example, a smart home may have a smart thermostat with manual controls, a variety of sensors providing data points for continuous security analysis (such as protection against potential break-ins, extreme temperatures, and flooding), voice-activated personal assistants, and digital control through a mobile app. To accomplish their goals, users may have to interact with the system through a combination of voice commands, gestures, screen interfaces, and physical controls. Although significant strides have been made to understand the impact of consumer IoT solution adoption through an integrated approach to the technology acceptance model (TAM) (See Gao & Bai, 2014), additional research is needed to further the understanding of user adoption to IoT systems and the implications of a broad collection of heterogeneous interactions. In addition, from the design perspective, the heterogeneity of communicating objects in a typical IoT context raises important and non-trivial questions about how to achieve the necessary standardization of communication while maintaining the component heterogeneity that contributes to the richness of the system capabilities as a whole.

5 Thematic Research Opportunities

In Section 4, we discussed the IS characteristics that change based on the introduction and inclusion of IoT elements. The intent was to highlight areas of important foundational scholarly enquiry on IoT and its implications for characteristics of systems that include IoT elements. In this section, our perspective changes: we explore the ways in which IoT opens up research opportunities based on its impact on four major thematic domains: organizations, technology, individuals, and society. For each domain, we highlight possible topics and discuss the issues and potential significance of IoT within that domain followed by a commentary on the theoretical implications. Our aim is not to provide an all-encompassing coverage of all possible avenues of IS inquiry; instead, our intent is to highlight a few key potential topics and to provide an illustrative agenda for addressing the impact of emerging IoT phenomena on major domains by drawing on the core characteristics and foundational implications outlined in Sections 3 and 4, respectively.

5.1 Impact on Organizations

A lingering question in the conversation around IoT in organizations (aligning with the *IT and organizations* theme in Sidorova et al. (2008)) today is as follows: how can we strategically position an organization to leverage IoT, while minimizing the impact of the challenges associated with it? The gains comprise the accruable benefits, value, and competitive advantage, whereas the pains include the disruption and challenges that may be associated with IoT, such as difficulties in getting access to qualified personnel (Shim et al., 2019). IoT has potential for different types of organizations but depending on the type of outputs (products, services or technology), its utility and value appear to unfold differently. As demonstrated by prior research (Kleis, Chwelos, Ramirez, & Cockburn, 2012; Kohli & Grover, 2008; Nambisan, 2013), emerging IT innovations, such as IoT, can create value for organizations by a) enabling improvements in processes and organizational efficiency; b) enabling digitalization and enhancements of products or service offerings; and c) increasing brand value plus customer engagement, among many others (Baiyere, Salmela & Tapanainen, 2020; Endres, Indulska, Ghosh, Baiyere, & Broser, 2020). There is, therefore, a need for IS research to examine how organizations can systematically build effective strategies to gain value from IoT.

Additionally, as IoT can be seen as both a digital innovation opportunity as well as a digital transformation opportunity, many organizations are still trying to figure out the implication of each dimension and how to juggle these along with their many other priorities (Baiyere et al., 2020; Weill & Woerner, 2018). In an era that is characterized by continuous introduction of new digital innovations, organizations see IoT as a channel with which to further infuse digitalization in their offerings. Similarly, IoT is an important asset in the process of digital transformation. Although some see it as an opportunity to incorporate digitalization into their products, others see this as a means to make gains through improved operational efficiency (Baiyere et al., 2020; Endres et al., 2020). Some realize that its emergence could lead to significant disruption of their ability to achieve their goals and are exploring how to transform their organization to address the potential disruption. In essence, organizations are grappling with understanding how to leverage the opportunities of IoT as well as how to ensure that its disruptive tendencies (Baiyere & Hukal, 2020) do not catch them by surprise. Organizations are trying to understand what it means for their business models, their product portfolio, and their operational processes (Endres et al., 2020). These are issues where IS research can draw from the implications of heterogeneity and composite affordance of IoT to illuminate our understanding of these research areas.

Specifically, in an industrial business context, a multilevel exploration of IoT research in IS can be readily gleaned from such a context, as industrial IoT (IIoT) opens up the possibility for a pan-organizational business setup (Daugherty, Banerjee, Negm, & Alter, 2014). This pan-organizational possibility unfolds as both an obstacle and opportunity, as companies need to assess their capabilities and engage in atypical partnerships so as to be able to leverage the opportunities of the IIoT. It becomes imperative that companies in such contexts think unconventionally about their customers, business models, trends, technologies, and capabilities needed to be a contender in such an ecosystem. Leveraging IIoT implies a transformation where traditional manufacturing companies begin to assume some attributes of an IT company. Hence, the dilemma for such companies will likely be more of an organizational challenge than a technical challenge and opens up research avenues across different levels, stakeholders, and industries. Research opportunities can be found in the dearth of knowledge in our understanding about the interface between the distinct worlds and levels that IoT is interconnecting. This also provides an opportunity for multidisciplinary studies, as many other disciplines would be needed to provide input or theoretical foundations that will inform us as we embark on these studies. In general, IS research is needed to better understand the requirements, models, and implications of these new interconnected worlds and the skills required to thrive in an emerging IoT era.

From a business and management perspective, crafting a profitable and sustainable business model around IoT is also a practical challenge that is worth investigating (Endres et al., 2020). The physico-digital nature of IoT innovations require business models that leverage both the physical and digital nature of such innovations. However, very few enterprises are proficient in creating and capturing value across the physical and digital domains. Typically, organizations are able to derive value from their investments in new innovations based on how successful they are in deploying those innovations within a business model. Hence, the emergence of IoT as an important initiative of an organization would drive the search for business models that bring forth its potential value as well as leverage its dual digital and physical attributes. Studying ways to leverage IoT to survive, compete, and thrive in the emerging IoT-driven business environments are a valid consideration under this theme. The emerging body of knowledge about IoT implies that businesses are still trying to identify and implement unique and inimitable value propositions from IoT (Bilgeri & Wortmann, 2017; Dijkman, Sprenkels, Peeters, & Janssen, 2015; Leminen, Westerlund, Rajahonka, & Siuruainen, 2012). A dilemma for managers contemplating IoT lies in the appreciation of the significant promise of what is possible with IoT and the burden of uncertainties that abound in attempting to pursue it.

There are opportunities through which IS research could demonstrate relevance and contribute meaningfully to IoT research from a business and management perspective. An essential research agenda for IS in this regard involves bringing clarity to the befuddling complexity and misconceptions of IoT that proliferate both the practitioner and academic domains. Clarity of constructs, concepts, and limitations would be of value to theory building in this research endeavor. Achieving conceptual clarity will, at the same time, help practitioners to make sense of the actual possibilities versus the hyped possibilities, understand different application areas and their limitations, as well as provide guidance in engaging in IoT initiatives. Further, based on the issues highlighted above and the potential inherent in IoT from this perspective, IS researchers have the opportunity to generate theoretical insights that examine the extent to which our prior assumptions hold under the logic of value creation and capture in IoT. Such theoretical expositions can help us understand how value can be created, captured, and distributed within an organization and across business ecosystems. Examples of existing research streams that are potential avenues to draw from and to which theoretical contributions can be made include IT strategy, IT governance, IT security, digital innovations, digital transformation, economics of IT, business processes, digital workforce, digital business models, and many others.

Illustrative questions under the organizational perspective include: How well do IS theories account for the derivation of business value in the IoT era? Do we need new theories to capture business value of IoT? How can IS theories be adapted to capture the multilevel, composite affordance and heterogeneous nature of IoT? What are the organizing logics for leveraging IoT in a business context? What are the roles and responsibilities of IT organizations in the IoT era? What are the relevant theoretical underpinnings for unpacking the complex stakeholder ecosystems that are characteristic of the IoT business landscape? IoT-based products and services need to be embedded within larger legacy systems. How can businesses deal with the system integration challenge, given the physico-digital attribute of IoT? What forms of collaboration, open innovation, and co-creation are emerging in the era of IoT? How should IoT business models be conceptualized to address the challenges and economic opportunities afforded by IoT? What are the opportunities that IoT-based systems create in governmental and not-for-profit contexts? These are by no means an exhaustive list of open questions and potential research directions to be considered in future. They are provided to provoke and stimulate ideas around IoT and to serve as an illustrative list of potential research directions/issues that future scholarship may consider.

5.2 Impact on Technology Applications

With the ever-increasing massive number of devices that have the capacity to sense, communicate, and actuate in a dynamic setting, we are facing significant design and technical complexities. The implications of this, in turn, can be felt on the demands on the quality and reliability of the services that are dependent on these devices. The high likelihood of failures and security breaches is a real and imminent concern. It is, therefore, critical to pay attention to how these systems are designed. This domain is closely aligned with the IS development research area in Sidorova et al. (2008). IoT with its high level of uncertainty provides ample opportunity for research that looks into the fundamental principles of design, development, and functional capabilities, particularly from the perspective of the design principles and practices that inclusion of IoT capabilities requires. Another open research issue is the standardization of IoT devices and the mechanisms by which they communicate with each other. Due to the interwoven sociotechnical nature of IoT, studies on standardization would have possibilities in the context of technology as well as the application and practical use cases. A need for a shared understanding and lexicon for interoperability across different channels and different application scenarios is a potential opportunity for further IS inquiry. In achieving this, we believe there will be value in studies that also consider the heterogeneity, composite affordances, and behavioral semantics that are equally essential in the design and standardization of IoT applications.

Concern around IoT data is another issue worthy of consideration as a possible agenda item for IS research, as it drives to the heart of the physico-digital implications of IoT. Managing and consuming data from an IoT deployment presents significant challenges because data from diverse sources and devices need to be normalized. An IoT instance needs to congruently handle both historic and real-time data involving multiple deployment methods. These complexities create key data challenges that impact the ability to consume and fully utilize the data collected. Typically, IoT application deployments consist of massive numbers of devices and endpoints including cameras, microphones, smoke alarms, and sensors using a variety of communication standards. These devices are transmitting vast amounts of heterogeneous data, creating a significant challenge in managing the data as each device may have a different protocol, transport requirements, and structure. Further, the data may be coming from disparate sources that have specific restrictions and needs. For example, a smart city deployment may collect video streams and traffic information from government sources that require strict security compliance (Bassoli et al., 2007). Data then may enter in stream from private data sources handling user profile information from IoT applications running on mobile devices. As users are directed to open parking spaces from the city's applications, local restaurants and shops could be notified so that they can push promotions, such as sales and lunch specials, to interested potential customers.

From a multilevel perspective, all these data come together to help the city intelligently manage their infrastructure and bring in more visitors. It helps local businesses increase their foot traffic and conversion rates, and the lives of both citizens and tourists are improved by time savings and stronger sense of security. However, there is still a lot of ground to cover in our understanding of how to derive value from the vast amount of heterogeneous data, coming from devices with varying protocols and technical plus physical specifications. Within this challenge lies an opportunity for IS research from a technical and design perspective. In addition, IS is well-positioned to address questions related to the role of data in the context of IoT—particularly, big data analytics. This could range from exploring the perspective of the required high-level analytics infrastructure, the integration of data from IoT-focused systems with other organizational systems, and the management of data at the system level. IS has the potential to contribute in a significant way to the discussion on implications and potential consequences of big data (Markus & Topi, 2015). It has the same potential in matters related to IoT and this is likely to be an area where the discipline can provide truly distinctive value.

Additionally, continually topping the charts for concerns over IoT deployments is the exponential increase in security risks associated with the rapid increase of connected devices. IDC has predicted that 90% of IT networks will have an IoT-based security breach (Turner, MacGillivray, Gaw, Clarke, & Morales, 2014). Due to the vast disparity of the types of devices, protocols, applications, and other elements of an IoT environment, there may be a natural barrier to entry for IoT exploits and attacks. Paradoxically, this can also open up various entry points for attack, as it equally implies more vulnerability outlets for malicious infiltrations. The increasing number of IoT deployments and the potential value of the data in these environments may entice attacks across all industry, government, and consumer IoT systems. Policy regulations as well as security protocols, therefore, need to address vulnerabilities from the physical IoT device end points through the digital data pipeline to both public and private cloud infrastructure, as well as the transfer of data to end devices consuming the insights from analytics. This further illustrates the need to take a multilevel perspective in our investigation of IoT as an imperative particularly in the context of IoT security.

In terms of application design and user experience, IoT devices are highly specialized and, therefore, vary drastically depending on the application. The ability of IoT applications to deliver value to users is dependent on highly complex architectures that span across a vast array of various device types, platforms, and network/infrastructure paths. Due to the very nature of these architectures, there are many points that may cause friction between a user's experience and the IoT deployment. Additionally, users may interact with various devices across the stack through gestures, voice commands, eye tracking, bio-informatics, and traditional graphical user interfaces (GUIs) (Rowland & Charlier, 2015). The spectrum of research opportunities continues to broaden. For example, considering IoT application design and user experience in the context of the health domain, the role of wearables in healthcare will continue to grow and the process of optimizing patient experience continues. Although some research has been conducted, additional models, design practices, and user experience (UX) measures are needed to evaluate various device types that may have different functions across the entire stack of physical and digital domains. These open up gaps that need to be understood and addressed by future research.

5.3 Impact on Individuals

IoT capabilities have a potential major impact on individuals, both within and outside organizational contexts, leading to significant new research opportunities in the *IT and Individuals* research theme (Sidorova et al., 2008). For example, adoption, use, and benefits realization are key focal points in the domain of technology adoption (see also Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong, & Xu, 2016b). Recent work has suggested that in a variety of consumer contexts, adoption and use are voluntary (see Venkatesh, Rai, Sykes, & Aljafari, 2016a; Venkatesh et al., 2016b). The social changes resulting from IoT devices can be far-reaching resulting in various lifestyle changes (Mitchell, 2004). It is already seen that with smartwatches, work-life balance and intrusiveness to personal time are affected even more than was the case with mobile phones only. It is important to note a need for more and continuing research on such non-work individual IoT adoption and use, especially because much of IS research on the topic of adoption has focused on technologies targeting employees. However, with IoT, personal non-work use of such technologies (e.g., in the home) become more salient as a component to consider in future theorizing. We suggest that this has the potential to be a fertile arena for IoT research and to reorient many taken-for-granted assumptions (see Schuetz & Venkatesh, 2020).

Related but distinct from the impact on individual behavior is the large-scale impact on healthcare. Perhaps the greatest social transformation potential, especially in the positive direction, is fostered in healthcare, be it in developed or developing countries. With numerous wearables, the potential positive impact on healthcare has grown. In a developing country context, large-scale societal transformation has been possible with the advent of even traditional technologies such that with IoT, even greater change can be engendered to achieve empowerment of women (Venkatesh, Shaw, Sykes, Wamba, & Macharia, 2017). Various healthcare issues have become a focus and IoT adoption in healthcare for quality improvement is sure to be a critical topic. Although the adoption decision may continue to be voluntary, use of IoT devices may be involuntary because data transmittal in many cases is automatic. Questions regarding adoption become particularly complex in the healthcare context where the role of patients as providers of data is essential to improve healthcare delivery and in the prevention of problems (Chatterjee et al., 2018). For example, even though a healthcare professional might set up a wearable IoT device correctly, the patient can subsequently intentionally or unintentionally modify the settings that compromise the goals of the healthcare provider and, in turn, compromise the quality of the care. All these factors point to the need for a much more sophisticated and nuanced look at the IoT adoption and use contexts. Specifically, IoT adoption and use studies should help advance scientific knowledge tied to this key new technological development. A study of design features of specific IoT technologies and how they may, in turn, influence key predictors (e.g., performance expectancy) in technology adoption models will be a useful direction that not only tackles this problem from a social/behavioral perspective, but also from a design science perspective (Baskerville et al., 2018; Venkatesh et al., 2016a; for an example, see Zhang, Venkatesh, & Brown, 2011), with potential input also from prior research on mobile technology adoption and use (see Thong, Venkatesh, Xu, Hong, & Tam, 2011).

A second set of research opportunities, which build on the idea of context presented in the first set, includes additional opportunities in the healthcare context. Earlier, we discussed practical issues related to IoT in healthcare. IoT devices go a step further in being far more intrusive and intimate in terms of how they relate to a patient's life and activities. It is reasonable to expect that the theoretical approaches that will be used have to be far more inclusive in terms of individual reactions to technologies that will actively record, monitor, and share very private information. Going a step further, IoT technologies in healthcare settings for potential use by patients who are faced with various ailments signify situations of varying levels of threats to one's well-being or even life (Chatterjee et al., 2018). This will necessitate a paradigm shift in terms of what theories and constructs drive adoption and use.

Third, another specific area that emerges from the general notion of individual use context and has a major impact on use is security and privacy. Oriwoh, Sant, & Epiphaniou (2013) draw attention to the fact that new cybercrimes are typically triggered as new technologies are developed and deployed. They claim that IoT is also likely to be accompanied by a wave of privacy and security breaches. Given the rate of change of technology and, in particular, the anticipated rate of diffusion and adoption of IoT, legislation will inevitably lag behind IoT. Thus, as IoT gets assimilated, there will be a time lag because of the ability of state and federal statutes to keep up with the developments. Indeed, there is a need for governance and legal oversight over how IoT operates even now when the technology is in its formative stages. Our domestic, work, and social environments are going to be profoundly influenced by IoT and, therefore, legal and policy discussions around the IoT should be seen as critical for its development. Research could provide answers to associated issues, such as avoiding unlawful processing, traceability, and profiling of persons, and leading to a design of data protection friendly technologies. In this context, identification issues are at stake, embracing object identifiers, network addresses as well as resolution and discovery functions from a scholarly perspective. In terms of security in IoT, security researchers within the IS community have the competencies to be able to provide an important new set of perspectives, particularly because they are able to seamlessly integrate policy and technical perspectives (Kayworth & Whitten, 2010). Although privacy and security—and the concomitant issues surrounding trust and risk—have been studied previously in IS research, IoT technologies in various contexts, including but not limited to healthcare, do need to be targets of rigorous research. This is essential so that we can improve our understanding of how existing knowledge related to these key concepts will generalize to IoTs and what new constructs/mechanisms/theories may be necessary. Here too, we emphasize that various contexts may result in the need for various new constructs/mechanisms/theories.

5.4 Impact on Society

A societal perspective is naturally an amalgamation of the organizational, technology, and individual perspectives discussed earlier. A society-level research agenda deserves separate attention, as many of the implications of the proliferation of IoT manifests at this level. It is also a pertinent call for IS research to strive for societal relevance beyond ivory tower theorizing with little consideration of contribution to the larger society. Recent calls have highlighted the need for IS research to engage with the societal impact and consequences of technology (Majchrzak, Markus, & Wareham, 2016). In this regard, we highlight three broad avenues for IoT research at this level: societal benefits, consequences, and ethics.

In terms of research on the societal benefits of IoT, a lot has been already discussed in terms of the promise of IoT across all levels. These range from the significant role of IoT in various initiatives, such as smart city, smart grids, and smart agriculture. It is, however, necessary to unpack the mechanisms and processes through which these promises and intended consequences of IoT can be achieved in practice. Key questions of concern for IS research include: how can IoT can serve as a catalyst for achieving national progress and social transformation? In particular, how can the advances promised by IoT be accommodated within the existing social and institutional frameworks? Or conversely, how should the existing frameworks be modified to enable society to harness value inherent in IoT applications? These questions would require pushing the envelope in multidisciplinary and multilevel research in various areas, such as and legislation, policy making, as well as constructive use of IoT for the common good, such as climate change and disaster management (e.g., earthquakes). As Wirtz, Weyerer and Schichtel (2018) note, IoT is emerging as a source of growth and innovation, but there is a need for efforts on how to tap its potential in order to improve the use of public resources and increase the effectiveness of public services for the society. In line with this, it would be important for future research to think about the value of context and question a “one-size-fits-all” paradigm, especially as we develop societal research around IoT.

As Kling (2003) notes, not all technological advances are universally positive. Hence, there is a need for research that explores the undesirable consequences of IoT at a societal level. For example, IoT has been lauded for ushering in new approaches that may or may not require having a human in the loop and eliminate human errors and related issues. Yet, beneath this glamorous outlook lies the uncomfortable reality that this implies many jobs may become obsolete. This is reminiscent of the old argument about machines and automation replacing people and taking away their jobs (Brynjolfsson & McAfee, 2014). Dilemmas such as this call for scholarly attention to how we can leverage the benefits of IoT while minimizing its negative implications on society. On a related note, an optimist would argue that technology creates as many jobs as it destroys. Yet, even this view exposes a different set of societal issues—e.g., education. If jobs are not taken away but reconfigured, how should we educate the future workforce of tomorrow for these new jobs of the future? Given the position of IS as an interdisciplinary field that straddles technical, business and social aspects, IS has a pivotal role in informing educational policy and championing research on how to answer the questions about educating for a world where IoT is pervasive and the norm.

Lastly, from an ethical perspective, those who undertake the planning, development, and operation of IoT systems have obligations to assure information integrity and overall contribution to the public good (Fidler & Rogerson, 2001). The concept of disclosive ethics (Brey, 2000) is particularly important in the context of new emerging technologies, such as IoT (Zuboff, 2019). Brey (2000) argues that complex technologies bring with them new moral problems precisely because of their complexity and opaqueness for non-experts. Because of this, technologies that appear morally neutral may, in fact, embody significant normative implications (Mitchell, 2004) and hence, there is a need for revealing and disclosing such characteristics (Mingers & Walsham, 2006). Introna (2005) gives an example of disclosive ethics concerning facial recognition systems. Social justice includes problems of digital divide caused by the lack of access to the technological infrastructure (European Comission, 2008). As the general research theme of IT ethics continues to grow in importance, we see, therefore, particular challenges with respect to the development and deployment of IoT devices. These challenges form part of the emerging research agenda in which the IS community can provide value, especially as we have long engaged with the digital realm and can benefit from collaborating with scholars from other disciplines like sociology in attending to the multilevel, heterogeneous, and composite affordance of IoT implications. Lessons learned from IS research on the implications and potential consequences of big data and analytics (Markus & Topi, 2015) can provide guidance for similiar scholarly work in the context of IoT. Another example is the critical issue of decentralization, particularly considering the practical, social and ethical challenges of having one or two global digital platforms centrally controlling most IoT data—what Zuboff (2019) calls surveillance capitalism.

6 Conclusion and Recommendations

We have highlighted broad focal areas that are indicative of how the IS discipline can provide distinctive contributions to scholarly work on IoT. These wide-ranging categorizations help in articulating the different areas of inquiry in the context of prior research classifications. This division into categories should not, however, preclude the examination of each agenda item within other categories. To the contrary, we posit that the multidisciplinary nature of IoT will warrant studies that cross over multiple modes of enquiry and require blurring the lines between these categories. The wide umbrella of IoT is likely to provide a rich variety of research questions that IS researchers are uniquely capable of addressing and have the competencies to provide significant value to a variety of stakeholders. In many cases, a synergy in the perspective of the design and behavioral paradigms may yield even more interesting insights. We have suggested two separate perspectives on the research agenda: one focused on the conceptual implications on IoT on IS research as a whole and the other one focused on three thematic domains (organizations, technology, and individuals in society). The discussion has demonstrated that many IoT-related research topics cross the boundaries of implications and domains—the issues are not silos but span across perspectives. We encourage the IS community to integrate research approaches and conduct cross-disciplinary research on IoT.

In summary, we highlight some of the key research agenda items cutting across all the themes—particularly, the call for future research and indicative research questions that we have so far discussed. We summarize this in Table 2. It should be noted that these are meant to be illustrative and many are multilevel and not restricted only to the indicated levels or themes. We have adopted the thematic representation used in the discussion so far mainly for simplicity.

Table 2. Overview of some IoT research opportunities

Theme	Sample research opportunity
Organization	• Build effective organizational strategies to create, capture and deliver value across the physical and digital domains that characterize IoT. • Exploration of how organizations should position themselves to accrue gains and avoid disruptive pains of IoT innovations. • Understanding the requirements, models, and implications of business in an interconnected world and the changing role of humans in the loop. • Developing and acquiring requisite skills and capabilities required to thrive and compete in an IoT era. • Clarifying the complexity and misconceptions of IoT that proliferate—clarity of constructs, concepts, and frameworks to enable cumulative theory building. • Rethinking and updating prior assumptions with the emerging organizing logics and peculiarity of IoT. • How can IS theories be adapted to capture the multilevel, composite affordance and

	heterogeneous nature of IoT for organizational research? • What are the roles and responsibilities of IT departments in the IoT era?
Technology	• Studies that examine the fundamental design principles, development practices, and functional capabilities required for IoT innovations. • Standardization of IoT devices and the mechanisms by which they communicate with each other given the varying pockets of IoT innovations. • How can we deal with the system integration challenges, given the physico-digital attribute of IoT that cuts across multiple discipline and expertise? • Consider the heterogeneity, composite affordances, and behavioral semantics needed in the design and standardization of IoT applications. • Addressing the complexities and challenges that impact the ability to collect, consume, and utilize data. • Exploration of the integration of data from IoT-focused systems with other organizational systems and the management of data. • Addressing concerns over IoT deployments and the exponential increase in security risks associated with the rapid increase of connected devices. • Research on models, design practices, and user experience across various devices with different functions over the stack of the physico-digital continuum.
Individual	• Implications of various lifestyle changes resulting from IoT use by individuals and the far-reaching consequences. • The potential for non-work IoT to be a fertile arena for research that reorients taken-for-granted assumptions from prior dominant organization perspectives. • Need for a much more sophisticated and nuanced look at the IoT adoption and use contexts, e.g., healthcare. • Study of design features of individual-focused IoT and how they may influence key predictors (e.g., performance expectancy) in technology adoption models. • Theoretical considerations that are more inclusive in terms of individual reactions to IoT that actively record, monitor, and share very private information. • Provide answers to issues, such as unlawful processing, traceability, and profiling of persons, and design of data protection friendly IoT technologies. • Improve our understanding of how existing IS knowledge/concepts generalize to IoT and what new constructs/mechanisms/theories may be needed. • Unpack the mechanisms and processes through which the promises of IoT and intended consequences of IoT can be achieved in practice.
Society	• What are the relevant theoretical underpinnings for unpacking the complex stakeholder ecosystems that are characteristic of the IoT business landscape? • What are the opportunities that IoT-based systems create in governmental and not-for-profit contexts? • Policy regulations, as well as security protocols, to address vulnerabilities from the physical IoT device end points, data pipeline, and cloud infrastructures. • Studies on governance and legal oversight over how IoT operates even now when the technology is in its formative stages. • Opportunity for IS research to strive for societal and practical relevance beyond ivory tower theorizing. • Engagement with the societal impact and consequences of IoT such that we can leverage the benefits while minimizing its negative implications on society. • How can IoT serve as a catalyst for achieving national progress and social transformation? • How can the advances promised by IoT be accommodated within the existing social and institutional frameworks or how should frameworks be altered? • How could we inform educational policies for a workforce of the future where IoT is pervasive and the exact role of humans is still ambiguous? • How can cross-disciplinary research be leveraged to handle emerging ethical and moral dilemmas of incorporating IoT into society?

A natural point of opportunity for the IS discipline with regard to IoT relates to the contextualization of extant theory in the IoT context. In all likelihood, although existing theories provide a useful starting point, significant contextualization and modification of these theories is likely to be necessary to understand the IoT phenomenon in general, with further nuanced treatment necessary for particular technologies. Broadly, Johns (2006) noted that contextualized, rather than general, theories are particularly important. Alvesson and Karreman (2007) go a step further by suggesting that testing existing theories in a new context and the resulting breakdown creates opportunities for new knowledge creation. We have organized the agenda for IoT research into four thematic domains as areas impacted by IS: organizations, technology, individuals, and society. Under each theme, we have highlighted the challenges and opportunities that open up research avenues for IS. Based on the outlined agenda, we present the overarching issues that are likely to be particularly promising for IS research in the context of IoT.

First, the IS discipline is well positioned to address questions regarding how IoT can transform organizations. Our discipline's ability to integrate in-depth understanding of IT with deep knowledge of a domain of human activity, such as business, health care, and government, put us in the forefront of studies that analyze the transformational power of IoT. We are particularly well positioned to analyze and propose various structural and process models to maximize IoT's potential to generate value. More specifically, IS research on business process management, design, and transformation (Rosemann & Vom Brocke, 2015) should form a strong foundation for understanding the interdependencies in systems that depend on IoT. Further, IS research can bring clarity to the conceptual complexity and ambiguity that makes it difficult to make sense of the true opportunities created by IoT technologies.

Second, managing the development of technology has always been an important area of study for IS (IS Development in Sidorova et al., 2008). Therefore, our discipline is well positioned to address questions related to issues in managing and organizing IoT development activities. Further, the IS discipline has particular strengths in addressing IoT strategy and governance issues. The IS discipline is well positioned to address implications and potential consequences of IoT, addressing the risks and potential pitfalls in addition to the undeniable benefits for organizations and their implications to broader management research. Design science as a paradigm may contribute in significant ways to the specification and design of IoT platforms and systems, providing an approach that is significantly broader than a narrow focus on technologies by many other disciplines (Baskerville et al., 2018; Chatterjee et al., 2018). This is particularly true in contexts that integrate generation, storage, and analysis of big data in IoT contexts, requiring both real-time processing of very large amounts of current data generated with a high velocity and integration of real-time data with even more historical data.

Third, IS research paradigms, such as design science and behavioral research, have the opportunity to uncover interesting insights about the impact of IoT on individuals and societies. We believe that the IS discipline is better prepared to understand issues related to IoT adoption and use than any other discipline is. Based on research on contextualization, we note that it is particularly important to develop contextualized theories to develop a deeper, more nuanced understanding of specific aspects of IoT technologies and systems built on them.

In summary, the key strength of the IS discipline contributing to IoT comes from our ability to examine a phenomenon from the social, technical, and business perspectives, and to further leverage these distinct research perspectives to provide theoretical and practical insights. Further, our distinctive capabilities in understanding and modeling how the various layers of this complex and highly interactive system work together, how the system as a whole can be harnessed to advance goals of human and organizational agents, and what the intended and potential unintended consequences of the IoT based systems are makes these potentially fruitful areas of contribution to IoT for IS researchers.

Acknowledgements

We would like to thank the editor and associate editor for their insightful guidance throughout the whole process. Our appreciation also goes to the four anonymous reviewers for their developmental feedback that immensely shaped and improved the paper. We thank the participants of the panel presentation at AMCIS 2017. We would also like to acknowledge the contribution of colleagues such as Alan Hevner, Marko Niemimaa, Markus Zimmer, Heli B., Said Tabet and Calvin Smith for their input and engaging discussions that have contributed to the development of the paper.

References

Abbasi, A., Sarker, S., & Chiang, R. H. L. (2016). Big data research in information systems: Toward an inclusive research agenda. *Journal of the Association for Information Systems*, *17*(2), 1–32.

Alvesson, M., & Kärreman, D. (2007). Constructing mystery: Empirical matters in theory development. *Academy of Management Review*, *32*(4), 1265–1281.

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, *54*(15), 2787–2805.

Baiyere, A., Hevner, A., Gregor, S., Rossi, M., & Baskerville, R. (2015). Artifact and/or theory? Publishing design science research in IS. In *Proceedings of the International Conference on Information Systems*.

Baiyere, A., & Hukal, P. (2020). Digital disruption: A conceptual clarification. In *Proceedings of the 53rd Hawaii International Conference on System Sciences*.

Baiyere, A., Salmela, H., & Tapanainen, T. (2020). Digital transformation and the new logics of business process management. *European Journal of Information Systems*, *29*(3), 238–259.

Baiyere, A., Venkatesh, V., Donnellan, B., Tabet, S. & Topi, H. (2016). IoT - Towards a research agenda for information systems. In *Proceedings of the Americas Conference on Information Systems.*

Barnaghi, P., Wang, W., Henson, C., & Taylor, K. (2012). Semantics for the Internet of Things: Early progress and back to the future. *International Journal on Semantic Web and Information Systems*, *8*(1), 1–21.

Baskerville, R. (2011). Individual information systems as a research arena. *European Journal of Information Systems*, *20*(3), 251–254.

Baskerville, R., Baiyere, A., Gregor, S., Hevner, A., & Rossi, M. (2018). Design science research contributions: Finding a balance between artifact and theory. *Journal of the Association for Information Systems*, *19*(5), 358–376.

Baskerville, R., Meyers, M., & Yoo, Y. (in press). Digital first: The ontological reversal and new challenges for IS. *MIS Quarterly*, 1–31.

Bassoli, A., Brewer, J., Dourish, P., Martin, K., & Mainwaring, S. (2007). Underground aesthetics: Rethinking urban computing. *Pervasive Computing, 6*(3), 39–45.

Benbasat, I., & Zmud, R. W. (2003). The identity crisis within the IS discipline: Defining and communicating the discipline's core properties. *MIS Quarterly*, *27*(2), 183–194.

Bilgeri, D., & Wortmann, F. (2017). Barriers to IoT business model innovation. *Wirtschaftsinformatik*, *2*, 1–22.

Brey, P. (2000). Method in computer ethics: Towards a multi-level interdisciplinary approach. *Ethics and Information Technology*, *2*(2), 125–129.

Brynjolfsson, E., & McAfee, A. (2014). *The second machine age : Work, progress, and prosperity in a time of brilliant technologies*. W. W. Norton & Company.

Burton, B., Burke, B., & Blosch, M. (2016). Hype cycle for enterprise architecture, 2016. *Gartner Research*. Retrieved from https://www.gartner.com/en/documents/3384417/hype-cycle-for-enterprise-architecture-2016

Chatterjee, S., Byun, J., Dutta, K., Pedersen, R. U., Pottathil, A., & Xie, H. (Qi). (2018). Designing an Internet-of-Things (IoT) and sensor-based in-home monitoring system for assisting diabetes patients: iterative learning from two case studies. *European Journal of Information Systems*, *27*(6), 670–685.

Chui, M., Löffler, M., & Roberts, R. (2016). The Internet of Things. *McKinsey Quarterly.* Retrieved from https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-internet-of-things

Da Xu, L., He, W., & Li, S. (2014). Internet of Things in industries: A survey. *IEEE Transactions on Industrial Informatics*, *10*(4), 2233–2243.

Daugherty, P., Banerjee, P., Negm, W., & Alter, A. E. (2014). Driving unconventional growth through the industrial Internet of Things. Accenture. Retrieved from https://www.accenture.com/us-en/_acnmedia/Accenture/next-gen/reassembling-industry/pdf/Accenture-Driving-Unconventional-Growth-through-IIoT.pdf

Dijkman, R. M., Sprenkels, B., Peeters, T., & Janssen, A. (2015). Business models for the Internet of Things. *International Journal of Information Management*, *35*(6), 672–678.

Dlodlo, N., Foko, T., Mvelase, P., & Mathaba, S. (2012). The state of affairs in Internet of Things research. *The Electronic Journal Information Systems Evaluation*, *15*, 244–258.

Endres, H., Indulska, M., Ghosh, A., Baiyere, A., & Broser, S. (2019). Industrial Internet of Things (IIoT) business model classification. In *Proceedings of the International Conference on Information Systems*.

Engeström, Y. (1990). When is a tool? Multiple artifacts in human activity. In *Learning, Working and Imagining. Twelve Studies in Activity Theory*. Helsinki: Otava-Konsultit.

European Comission. (2008). Internet of Things in 2020: A roadmap for the future. In *Rfid Working Group of the European Technology Platform on Smart Systems Integration (Eposs)*. Retrieved from http://www.smart-systems-integration.org/public/documents/publications/Internet-of-Things_in_2020_EC-EPoSS_Workshop_Report_2008_v3.pdf

Fichman, R. G., Kohli, R., & Krishnan, R. (2011). The role of information systems in healthcare: Current research and future trends. *Information Systems Research*, *22*(3), 419–428.

Fidler, C., & Rogerson, S. (2001). A practical perspective of information ethics. In P. Goujon & B. H. Dubreuil (Eds.), *Technology and Ethics: A European Quest for Responsible*, pp. 305–325.

Forman, C., Goldfarb, A., & Greenstein, S. (2005). How do industry features influence the role lf location on internet adoption? *Journal of the Association for Information Systems*, *6*(12), 383–408.

Fürstenau, D., Baiyere, A., & Kliewer, N. (2019). A dynamic model of embeddedness in digital infrastructures. *Information Systems Research*, *30*(4), 1319–1342.

Gao, L., & Bai, X. (2014). A unified perspective on the factors influencing consumer acceptance of Internet of Things technology. *Asia Pacific Journal of Marketing and Logistics*, *26*(2), 211–231.

Gholami, R., Watson, R. T., Molla, A., Hasan, H., & Bjørn-Andersen, N. (2016). Information systems solutions for environmental sustainability: How can we do more? *Journal of the Association for Information Systems*, *17*(8), 521–536.

Goles, T., Hawk, S., & Kaiser, K. M. (2008). Information technology workforce skills: The software and IT services provider perspective. *Information Systems Frontiers*, *10*(2), 179–194.

Greenberg, A. (2015). *Hackers remotely kill a Jeep on the highway—with me in it. WIRED*. Retrieved from https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/

Greenfield, A. (2006). *Everyware : The dawning age of ubiquitous computing*. New Riders.

Hernandez, G., Arias, O., Buentello, D., & Jin, Y. (2014). Smart Nest thermostat : A smart spy in your home. In *Black Hat USA*. Retrieved from http://www.cisco.com/web/about/ac79/docs/innov/IoT

Iera, A., Floerkemeier, C., Mitsugi, J., & Morabito, G. (2010). The Internet of Things. *IEEE Wireless Communications*, *17*(6), 8–9.

Introna, L. D. (2005). Disclosive ethics and information technology: Disclosing facial recognition systems. *Ethics and Information Technology*, *7*(2), 75–86.

Ishii, H., & Ullmer, B. (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '97*, 234–241.

ITU. (2005). ITU Internet Reports. The Internet of Things. International Telecommunication Union. Retrieved from https://www.itu.int/dms_pub/itu-s/opb/pol/S-POL-IR.IT-2005-SUM-PDF-E.pdf

Johns, G. (2006). The essential impact of context on organizational behavior. *Academy of Management Review*, *31*(2), 386–408.

Kayworth, T. R., & Whitten, D. (2010). Effective information security requires a balance of social and technology factors. *MIS Quarterly Executive*, *9*(3), 163–175.

Kees, A., Oberländer, A., Röglinger, M., & Rosemann, M. (2015). Understanding the Internet of Things: A conceptualisation of business-to-thing (B2T) interactions. In *Proceedings of the 23rd European Conference on Information Systems*.

King, J., & Lyytinen, K. (Eds). (2006). *Information systems: The state of the field*. John Wiley & Sons.

Kleis, L., Chwelos, P., Ramirez, R. V, & Cockburn, I. (2012). Information technology and intangible output: The impact of IT investment on innovation productivity. *Information Systems Research*, *23*(1), 42–59.

Kling, R. (2003). *Computerization and controversy: Value conflicts and social choices*. Morgan Kaufmann.

Kohli, R., & Grover, V. (2008). Business value of IT: An essay on expanding research directions to keep up with the times. *Journal of the Association for Information Systems*, *9*(1), 23–39.

Leminen, S., Westerlund, M., Rajahonka, M., & Siuruainen, R. (2012). Towards IoT ecosystems and business models. In *Internet of Things, smart spaces, and next generation networking.* Heidelberg: Springer, pp. 15–26.

Leonardi, P. M. (2011). When flexible routines meet flexible technologies: Affordance, constraint, and the imbrication of human and material agencies. *MIS Quarterly*, *35*(1), 147–167.

Leonardi, P. M., Nardi, B. A., & Kallinikos, J. (2012). *Materiality and organizing: Social interaction in a technological world*. Oxford University Press.

Li, S., & Xu, D. (2015). The Internet of Things: A survey. *Information Systems Frontiers*, *17*(2), 243–259.

Lopez, J. (2016). *Putting digital business to work in 2015*. Gartner.

Lyytinen, K., & Yoo, Y. (2002a). The next wave of nomadic computing. *Information Systems Research*, *13*(4), 377–388.

Lyytinen, K., & Yoo, Y. (2002b). Ubiquitous computing. *Communications of the ACM*, *45*(12), 63–96.

Majchrzak, A., Markus, M. L., & Wareham, J. (2016). Designing for digital transformation: Lessons for information systems research from the study of ICT and societal challenges. *MIS Quarterly*, *40*(2), 267–277 .

March, S., Hevner, A., & Ram, S. (2000). Research commentary: an agenda for information technology research in heterogeneous and distributed environments. *Information Systems Research*, *11*(4), 327–341.

Markus, M. L., & Topi, H. (2015). *Big data, big decisions for government, business, and society. Report on a research agenda setting workshop*. National Science Foundation. Retrieved from http://dl.acm.org/citation.cfm?id=2849516

McCullough, M. (2004). Digital ground: Architecture, pervasive computing, and environmental knowing. In *Digital Ground*. MIT Press.

Mingers, J., & Walsham, G. (2006). Towards ethical IS: The contribution of discourse ethics. In the *Proceedings of the International Conference on Information Systems*.

Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of Things: Vision, applications and research challenges. *Ad Hoc Networks*, *10*(7), 1497–1516.

Mitchell, W. J. (1996). *City of bits: space, place, and the infobahn*. The MIT Press.

Mitchell, W. J. (2004). *Me++: The cyborg self and the networked city*. MIT Press.

Nambisan, S. (2013). Information technology and product/service innovation: A brief assessment and some suggestions for future research. *Journal of the Association for Information Systems*, *14*(4), 215–226.

Norman, D. A. (1999). Affordance, conventions, and design. *Interactions*, *6*(3), 38–43. https://doi.org/10.1145/301153.301168

Norman, D. A. (2008). The way I see IT signifiers, not affordances. *Interactions*, *15*(6), 18–19.

Oriwoh, E., Sant, P., & Epiphaniou, G. (2013). Guidelines for Internet of Things deployment approaches—The thing commandments. *Procedia Computer Science*, *21*, 122–131.

Orlikowski, W. J., & Iacono, C. S. (2001). Research commentary: Desperately Seeking the “IT” in IT research—A call to theorizing the IT artifact. *Information Systems Research*, *12*(2), 121–134.

Patterson, D. A., & Hennessy, J. L. (2013). *Computer organization and design MIPS edition: The hardware/software interface*. Newnes.

Pitt, L. F., Watson, R. T., & Kavan, C. B. (1995). Service quality: A measure of information systems effectiveness. *MIS Quarterly*, 173–187.

Pogue, D. (2015). Hackers at the Wheel. *Scientific American*, *313*(5), 30.

Qin, Y., Sheng, Q. Z., Falkner, N. J. G., Dustdar, S., Wang, H., & Vasilakos, A. V. (2016). When things matter: A survey on data-centric Internet of Things. *Journal of Network and Computer Applications*, *64*, 137–153.

Rosemann, M., & Vom Brocke, J. (2015). The six core elements of business process management. In vom Brocke & M. Rosemann (Eds.), *Handbook on Business Process Management 1: Introduction, Methods, and Information Systems* (pp. 105–122).

Rowland, C., & Charlier, M. (2015). *User experience design for the Internet of Things*. O’Reilly.

Schuetz, S., & Venkatesh, V. (2020). The rise of human machines: How cognitive computing systems challenge assumptions of user-system interaction. *Journal of the Association for Information Systems*, *21*(2), 460–482.

Shim, J. P., Avital, M., Dennis, A., Rossi, M., Sorensen, C., & French, A. (2019). The transformative effect of the Internet of Things on business and society. *Communications of the Association for Information Systems*, *44*(1), 129–140.

Sicari, S., Rizzardi, A., Grieco, L. A., & Coen-Porisini, A. (2015). Security, privacy and trust in Internet of Things: The road ahead. *Computer Networks*, *76*(1), 146–164.

Sidorova, A., Evangelopoulos, N., Valacich, J. S., & Ramakrishnan, T. (2008). Uncovering the intellectual core of the information systems discipline. *MIS Quarterly*, *32*(3), 467–482.

Stankovic, J. A. (2014). Research directions for the Internet of Things. *IEEE Internet of Things Journal*, *1*(1), 3–9.

Star, S. L., & Ruhleder, K. (1996). Steps toward an ecology of infrastructure: Design and access for large information spaces. *Information Systems Research*, *7*(1), 111–134.

Thong, J. Y. L., Venkatesh, V., Xu, X., Hong, S. J., & Tam, K. Y. (2011). Consumer acceptance of personal information and communication technology services. *IEEE Transactions on Engineering Management*, *58*(4), 613–625.

Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Digital infrastructures: The missing IS research agenda. *Information Systems Research*, *21*(4), 748–759.

Tratz-Ryan, B., Jones, N., Ingelbrecht, N., & Escherich, M. (2014). *Predicts 2015: Building a sustainable footprint for people, workplace and the Internet of Things*. Gartner.

Turner, V., Gantz, J., Reinsel, D., & Minton, S. (2014). *The digital universe of opportunities: Rich data and the increasing value of the Internet of Things*. IDC. Retrieved from https://www.emc.com/leadership/digital-universe/2014iview/index.htm

Turner, V., MacGillivray, C., Gaw, J., Clarke, R. Y., & Morales, M. (2014). IDC FutureScape: Worldwide Internet of Things 2015 predictions. In *IDC FutureScape*. IDC.

Velosa, A., Hines, J. F., LeHong, H., Perkins, E., & Satish, R. M. (2014). *Predicts 2015: The Internet of Things*. Gartner.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, *27*(3), 425–478.

Venkatesh, V., Rai, A., Sykes, T. A., & Aljafari, R. (2016a). Combating infant mortality in rural India: Evidence from a field study of eHealth kiosk implementations. *MIS Quarterly*, *40*(2), 353–380.

Venkatesh, V., Shaw, J. D., Sykes, T. A., Wamba, S. F., & Macharia, M. (2017). Networks, technology, and entrepreneurship: a field quasi-experiment among women in rural India. *Academy of Management Journal*, *60*(5), 1709–1740.

Venkatesh, V., Thong, J. Y., & Xu, X. (2016b). Unified theory of acceptance and use of technology: A synthesis and the road ahead. *Journal of the Association for Information Systems*, *17*(5), 328–376.

Vodanovich, S., Sundaram, D., & Myers, M. (2010). Digital natives and ubiquitous information systems. *Information Systems Research*, *21*(4), 711–723.

Von Roessing, R. (2016). Highwaymen to hackers. *Computer Fraud and Security*, *2016*(3), 13–15.

Weill, P., & Woerner, S. L. (2018). Is your company ready for a digital future? *MIT Sloan Management Review*, *59*(2), 21–25.

Wessel, L., Baiyere, A., Ologeanu-Taddei, R., Cha, J., & Jensen, T. B. (in press). Unpacking the difference between digital transformation and IT-enabled organizational transformation. *Journal of the Association for Information Systems*, 1–57.

Whitmore, A., Agarwal, A., & Da Xu, L. (2015). The Internet of Things—A survey of topics and trends. *Information Systems Frontiers*, *17*(2), 261–274.

Wiberg, M. (2018). *The materiality of interaction: Notes on the materials of interaction design*. MIT Press.

Wirtz, B. W., Weyerer, J. C., & Schichtel, F. T. (2018). An integrative public IoT framework for smart government. *Government Information Quarterly*, *36*(2), 333–345.

Wolcott, P., Press, L., McHenry, W., Goodman, S., & Foster, W. (2001). A framework for assessing the global diffusion of the Internet. *Journal of the Association for Information Systems*, *2*(1), 6–50.

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research*, *21*(4), 724–735.

Zhang, X., Venkatesh, V., & Brown, S. A. (2011). Designing collaborative systems to enhance team performance. *Journal of the Association for Information Systems*, *12*(8), 556–584.

Zuboff, S. (2015). Big other: surveillance capitalism and the prospects of an information civilization. *Journal of Information Technology*, *30*(1), 75–89.

Zuboff, S. (2019). *The age of surveillance capitalism: The fight for a human future at the new frontier of power*. Profile Books.

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