The Rise of an "Internet of Things": Fundamentals and Managerial Implications of Ubiquitous Information and Communications Technologies

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Technological Background

"Ubiquitous Computing" (Weiser 1991, 1993), "Pervasive Computing" (Satyanarayanan 2001, Estrin et al. 2002), "Things that think" (Gershenfeld 1999), "Ambient Intelligence" (Aarts et al. 2002), "Silent Commerce" (Ferguson 2002) – a plethora of novel terms has evolved in recent years that propagate the coming of a new paradigm shift in information processing. Common to all these concepts is the shared vision of a future world of everyday physical objects equipped with digital logic, sensors, and networking capabilities, which together form a so-called "Internet of Things" (IoT) (Das & Harrop 2001). Whereas computing power was a scarce resource in the former times of mainframe computers and PC's, the IoT bears the promise of omnipresent real-time access to information and services centred around arbitrary objects and users with their individual tasks and objectives.

More than 15 years ago, Mark Weiser, a researcher at the Xerox PARC, foresaw this development, and described it in his influential article "The Computer for the 21st Century" (Weiser 1991). Weiser coined the term "Ubiquitous Computing", referring to omnipresent computers that serve people in their everyday lives at home and work, functioning invisibly and unobtrusively in the background with the aim of supporting them in their work and activities, and to a large extent freeing them from tedious routine tasks. Whereas his ideas sounded rather utopian at the time, today the large-scale use of tiny computerised devices in everyday life seems realistic. The dramatic progress in the miniaturisation of computer components and a continuous fall in prices due to new production techniques and technological developments enable a multitude of new application scenarios (Bohn et al. 2003).

It is neither a single technology nor a specific functionality which is behind the IoT but rather a bundle of functions implemented by a diverse set of systems and technologies. IoT-related research is accordingly characterised by a multidisciplinary approach that includes aspects of electrical engineering, computer science, management research, psychology and many more (Satyanarayanan 2001). For this reason, the following list of an object's technological capabilities in the IoT can be regarded as typical but does not claim completeness :

- *Identification.* The transformation of physical objects into network nodes of the IoT requires a technique for unique identification, e.g., by means of an unambiguous numbering scheme. This identification allows the object to be linked with services and data which are stored on a remote server in the network.

- *Memory.* The object has storage capacity so that it can carry information on its past or future, e.g., a product that records its manufacturing steps. Storage capacity on the physical object allows for the creation of highly decentralized systems with individual objects knowing the business processes they are involved in.
- *Sensor technology.* The object collects information about its environment (temperature, light conditions, other objects, etc.), records it and/or reacts to it (referred to as "context awareness"). Organizations can thus learn more about their products' usage processes and utilize this information for offering novel services or improve their products' design.
- *Positioning & tracking.* Objects in the IoT may know their location (Positioning) or can be located by others (Tracking), for example at the global level by GPS or inside buildings by ultrasound. Information systems may thus reach out into the physical world and provide location-dependent service to users whenever and wherever they are needed.
- *Processing logic.* Objects in the IoT may be able to make decisions automatically without a central planning instance, e.g., in the sense of an industrial container which determines its own route through the supply chain. The IoT thus becomes not only an infrastructure for data collection, but rather offers the opportunity for changing the architecture of today's information systems by delegating decision-making authorities down to the outer edge of the network.
- *Networking.* In contrast to the simple pocket calculator, objects in the IoT have the capability to connect with resources in a network or even amongst themselves (referred to as "ad-hoc networking") for the reciprocal use of data and services. Every object may thus become an interface to employees within the organization, consumers, and partners in the supply chain.
- *User interface.* With the merging of computer and physical object come new requirements to be met by the user interface. This calls for new approaches similar to the mouse & desktop metaphor of graphical user interfaces, e.g., in the form of haptic interfaces.

Radio Frequency Identification Technology (RFID) perhaps represents the best-known example of an IoT-related technology which is poised for mass use (Sarma et al. 2001). The ability of an object to store a unique identification number and to report it to its environment constitutes the first step toward the integration of object and information, and provides the basis on which farther-reaching functionality can be built (Want 2004). RFID provides a variety of advantages compared to the classical barcode and contributes to the optimisation of several manual and error-prone processes in organizations. After the huge hype around RFID tagging in retail and beyond in recent years, we currently witness the rise of integrated networks of RFID devices and repositories, such as the EPCglobal Network (EPCglobal 2007), which can be regarded as the first building blocks of the forthcoming IoT infrastructure.

Managerial implications

Ongoing informatisation and interconnectedness of physical objects has become a research issue in various academic disciplines. Technological feasibility of many application scenarios has now become reality due to increased technological performance, standardisation efforts, miniaturisation and price decline. In parallel, the IoT has also attracted the interest of several companies and industries. On the long run, the IoT might become the enabling technology for new management principles, which makes use of fine-grained data on physical goods flows instead of statistics, extrapolations, and guesstimates (Fleisch & Dierkes 2003 ; Fleisch et al. 2005). From this perspective, the emergence of the IoT can be interpreted as the logical third wave of IS integration after the introduction of ERP systems and the Internet as we know it today.

With the development of corporate information management over the last decades, the scope of integration has been constantly expanded (Fleisch & Österle 2000). Here, "integration scope" describes the number of tasks which an enterprise or enterprise network performs in an information system. The following phases can be distinguished in this evolutionary process (cf. Figure) :

- *Phase 1.* In the initial stages of electronic data processing, the aim of informatising single functions within the firm was to achieve efficiency gains through the automational impacts on functions such as billing or job scheduling. Here, manual operations are transferred to the computer but remain unchanged. This results in isolated solutions, i.e., separate information systems which efficiently support individual operations.

- *Phase 2.* By informatising some of the most important functional areas of the firm such as, e.g., production or financial accounting, integration was achieved and thus the efficiency of entire departments improved. IT enabled the application of new methods for the first time, such as financial planning, through which business processes could be redesigned.
- *Phase 3.* The development of Enterprise Resource Planning (ERP) systems offered enterprises the possibility of introducing integrated processes across departments and/or across functions. This meant that consistent processes could be set up from the customer (e.g., sales, order entry) and to the customer (e.g., distribution, billing, payment receipt).
- *Phase 4.* In parallel with the introduction of ERP systems, some enterprises began creating closer networks with their customers or suppliers. In a first step, they started employing systems for electronic data interchange (EDI) in order to process mass transactions efficiently.

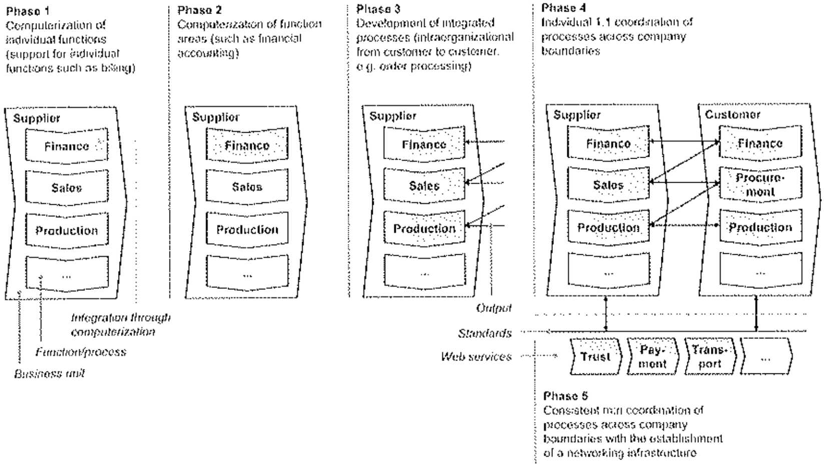

Figure : Expanding IS integration from isolated functions to interorganisational networks

- *Phase 5.* Today, novel information systems for supply chain management and e-commerce place the customer's processes at the forefront of process and IS design by enabling the integration of interorganisational processes and/or systems and thus a step toward the extended enterprise.

From this perspective on the evolution of integrated information systems, the IoT vision suggests a new quality of integration, which is no longer limited to the information flows of the digital world but also directly links processes in the physical world as well as the associated products (e.g., drugs, textiles) and means of production (e.g., pallets, machines). Thus, the scope of integration crosses the boundaries of information systems and pervades the world of physical goods and processes.

UC technologies have the potential to prevent the media break between physical processes and the associated information processing. They enable a fully automatable machine-to-machine relationship between real items and information systems by equipping the former with digital components. They help to reduce the costs of depicting physical resources and operations in information systems by assuming the role of mediator between the real and the virtual world (cf. Figure). A descriptive example is an industrial container that knows its position and contents and transfers this information automatically to the inventory management system of a distribution center on arrival at the docking door.

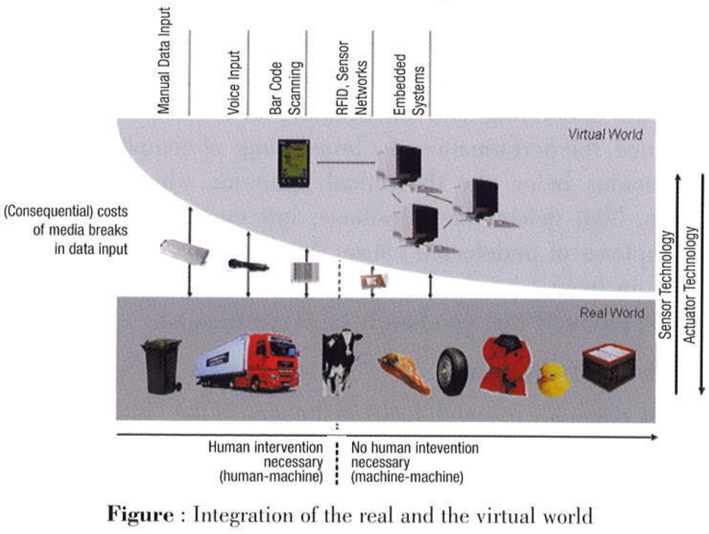

Figure : Integration of the real and the virtual world

The consequences of this technological change on management might best be described by an analogy from medical imaging. For centuries, the knowledge of physicians on the structure and the functioning of the human body were based on macroscopic investigations of corpses. Accordingly, the ability to recognize and treat a disease in a patient was limited by the physician's experience and the capacity of his five senses. It was not until the development of modern imaging procedures that an "anatomy of the living" was first made possible, e.g., by magnetic resonance imaging (MRI) introduced in the 1970s. The high-resolution images provided by these new technologies eventually led to an unprecedented level of precision and information in diagnostics.
While in our times the clinical procedures of a mediaeval "medicus" seem to be part of a far-distant past, many of the practices of planning and decision making in today's organizations take place under distressingly similar conditions. The management of processes in manufacturing, logistics, sales, and services, for example, largely depends on accurate information on the availability of parts, the status of machines and tools, the correct execution of workflows, customer behaviour on the sales floor, and many other things happening in the physical world. In practice, however, coarse-grained and untimely information is the rule owing to the fact that beyond highly automated processes no powerful measurement instruments exist that allow for zooming into the details of real-world events. Over time, companies have got used to such deficiencies. Moreover, strangely, the extensive use of information systems for improving the situation of managers can even contribute to the problem by hiding the nature of the underlying data and creating an illusion of accuracy. As a consequence, the performance of a broad range of complex physical processes remains below the theoretical optimum, which is reflected in stock-outs, high defect rates, spoilage, low customer satisfaction, and other symptoms of undetected cause. Against this background, the IoT will have an impact on the way companies manage their physical processes and products that can hardly be overestimated.

Research Contributions

In the past years, my research focus in the area of the "Internet of Things" was set on a number of socio-economic phenomena as well as on specific design questions surrounding its implementation. The following list provides an incomplete, but representative overview of some central research issues and example studies that I have been working on recently with my colleagues at the University of St. Gallen, ETH Zurich, and others :

- *Technology Adoption.* Despite the extensive discussion of the technological characteristics and expected benefits of RFID in the literature, only little is known about the actual determinants influencing RFID adoption. Based on a review of prior works, we constructed and empirically tested a structural model including factors related to the technology, the organization, and its environment. The underlying data were collected from EPCglobal, an international association of RFID standards adopters covering the whole supply chain and various industries. Our results suggest that top management support, perceived technology costs, and forces within the supply chain are the critical determinants of RFID adoption. We also found that benefit perceptions have a significant but negative influence, which might be explained by the different modes of adopting RFID. Based on our findings, we discussed implications for adoption research and organizations planning RFID deployments.
- *IT Business Value.* The business value of IT is one of the classical issues in the information systems field. In order to develop a better understanding of the specific value of RFID technology in retail, we conducted an explorative case study of an RFID project at Galeria Kaufhof, a subsidiary of Metro Group and one of the largest department store chains in Europe. The project encompassed a variety of RFID applications at the intersection of store logistics and customer service. The contribution that our study made to the literature was threefold. First, we described an innovative large-scale trial that went beyond what was done in earlier projects in several respects. The most fundamental difference from previous trials is the full integration of RFID event data with POS and master data, which for the first time offered the retailer the opportunity to directly observe and analyse physical in-store processes. Second, the heterogeneity of RFID applications implemented by Kaufhof allowed us to theorise about the effects that RFID may have on business processes from an IT value perspective. We developed a conceptual model to explain the different cause-and-effect chains between RFID investments and their impact on firm performance, the role of complementary and contextual factors, and the difficulty of assessing these impacts using objective performance

measures. Third, we compared the case to a prior trial conducted by Kaufhof about five years earlier. The differences between the lessons that the company learned in the two projects illustrate the impact of technological advances and standardisation efforts in recent years on managerial perceptions of RFID business value, which allows for the derivation of a number of useful implications for practice.

- *Business Process Redesign.* Beyond RFID-based identification, Real-Time Location Systems (RTLS) pose another example of a IoT-related technology in real-world use. Starting from the case example of an RFID-based RTLS implementation in a semiconductor fab, we investigated the value of RTLS information on the locations of physical objects in a complex production system to the problem of efficient job scheduling. For this purpose, we developed a simplified simulation model that captures the main characteristics of the real manufacturing process and propose a set of RTLS-enabled dispatching rules. Our results indicated that the use of RTLS technology provides the opportunity for new levels of process visibility and control in comparison to conventional material tracking systems. The benefits that can be drawn from the technology not only include an overall acceleration of the existing process but also an additional efficiency gain through novel dispatching rules that take into account real-time information on the logistic processes on the shop floor.
- *Business Model Innovation.* Besides improving individual business processes, the IoT also enables novel, so-called "smart" products and corresponding business models. One of our studies was concerned with the potential of usage-based pricing policies for such smart products on the foundation of detailed sensor data. We developed an analytical model of a supplier of machines and his customer that allowed us to compare usage-based pricing to a traditional scheme with fixed prices, and to determine optimal solutions for both parties. Based on these findings, we discussed the value of usage-based pricing on an operational as well as on a strategic level. The main conclusion that can be drawn from our research is that usage-based pricing does not provide any additional value that could not also be achieved by information sharing and joint price optimization. From a more strategic perspective, however, we found that the transfer of demand risk from the customer to the supplier implied by usage-based pricing might be

used as a strategic tool to attract new prospects and to enter new markets, but only to a lesser extent as a means to keep existing customers.

- *Societal Impact.* As the history of nuclear power, gene technology, and vaccination shows, novel technologies are not always regarded as a blessing but all too often also seen as a potential threat to health or personal freedom, among others. This also holds for RFID, which became known as the "spy chips threat" in some mass media worldwide. Against the background of the first RFID-Rollouts by large retailers in North America and Europe, we prepared a study of the perception of RFID technology as a risk to privacy. The objective of our contribution was to identify, at a relatively early phase of the risk development, strategic options with which RFID suppliers and users can positively influence the public acceptance of the technology. We proposed a strategic framework based on research findings on risk perception and technology acceptance as well as a set of options for coping with the public perception of RFID-related privacy risks.

It is understood that profound changes that are coming with the rise of the "Internet of Things" do not come over night. If the MRI metaphor mentioned in the previous section holds true, the IoT will provide legions of academic and industrial researchers and developers with challenging and fascinating questions for many years. Fruitful questions include not only the technological mechanisms, standards, and business benefits, but also the potential risks to privacy and data security. The question whether the benefits will outweigh the costs and risk perceptions will not least depend on the creativity and performance of researchers who accept the challenge. The race is on.

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