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Abstract

The term “ubiquitous technology” refers to any technology that extends common objects with data processing capabilities, e.g. RFID systems, wireless sensor networks or networked embedded systems. In this study, we uncover the mechanisms by which these technologies contribute to an increased business process performance. We apply the theory of task-technology fit to establish a model of the impact of ubiquitous technologies on business process performance. Based on expert interviews in a large standard software company, the potential of ubiquitous technologies for enhancing performance in a number of generic business processes is explored. Furthermore, we illustrate how our findings can be applied to identify value-creating ubiquitous computing applications in companies.

Keywords: Ubiquitous computing, Business process optimization, IT impact, Task-technology fit

1 Introduction

As the technological progress continues rapidly, ever cheaper, smaller and more powerful hardware is developed which enables the construction of miniature computers that can be embedded in real-world objects (Mattern 2005). The resulting “smart items” consist of a physical component (the object itself) and an information processing component, which enables the object to act intelligently. Current technologies used to enhance real world objects include radio frequency identification (RFID) systems, sensor networks and networked embedded systems. Furthermore, the capabilities of human beings can be enhanced using mobile technologies, thus pointing out another way of embedding information technology in the real world. The technologies mentioned jointly contribute to realizing the vision of ubiquitous computing that was defined by Weiser (1993) as “the method of enhancing computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user”.

As the number of deployed ubiquitous computing applications increases, the focus of researchers and practitioners alike shifts from technologically-driven considerations to the challenge of creating economically feasible applications. It needs to be examined how and in which industries, areas, situations and processes value-creating ubiquitous applications can be designed. As Fleisch and Tellkamp (2003) put it: “So far there is only limited knowledge on the impact of ubiquitous computing technologies on business processes and how applications based on these technologies can create value for companies”. Therefore, the aim of this exploratory study is to investigate the impact of ubiquitous technologies in a business context.

A review of literature dealing with the business impacts of ubiquitous technologies reveals that two different approaches for addressing the value of smart items are prevalent. On the one hand, there is a vast body of applied research that examines the application of ubiquitous technologies, often restricted to a single technology (e.g. RFID), in a specific company, a certain industry, or in particular business processes (Accenture 2002; Boushka et al. 2002; Lampe, Strassner & Fleisch 2004). The results can therefore not be generalised and transferred to companies that do not operate in the field covered by the study. In most cases, no theoretical foundation substantiates this research. On the other hand, there is a smaller body of research that examines the business impacts of ubiquitous technologies from a conceptual perspective (Heijden & Valiente 2002; Yoo & Lyytinen 2003; Strassner & Schoch 2002). This strand of research aims at developing frameworks that describe the impact of ubiquitous technologies on organizational performance, while considering few or no applications.

We aim at bridging the existing gap between theoretical and applied research by developing a framework of the business impact of ubiquitous technologies that is based on a broad range of potential applications and draws on well-established IT impact models as a theoretical foundation. The framework will illustrate how smart items contribute to improving business process performance and how value-creating ubiquitous computing applications can be identified. We seek to overcome the limitations of existing studies by concentrating on reference processes in order to ensure the general applicability of our framework. Reference processes are generic, best practice business processes supported by standard business software and are thus executed in many companies.

The framework is grounded in theory and builds on models of the impact of information technology in general and of ubiquitous and mobile technologies in particular. These foundations will be presented in the next section as well as the generic functionality of ubiquitous technologies and measures for process performance. In section 3, a comprehensive sample of business processes that can be optimized by ubiquitous technologies, will be presented. These processes were gathered in a series of expert interviews, which allowed to gain an in-depth understanding of the actual problems companies are facing. The general problems that can be solved by ubiquitous technologies are extracted from the compiled applications and incorporated in the research framework. The data analysis and derived implications are part of section 4. As the creation of solutions to these pertinent problems represents the main source of value of ubiquitous technologies, further companies can identify value-creating ubiquitous computing applications by determining in which processes the listed problems exist and reduce performance. A methodology for achieving this is presented in section 4.2.

2 Theoretical Foundations

2.1 Research Framework

As IT impact models explain how the features and functions of IT affect organisational and process performance, they are well suited for analyzing the business impacts of ubiquitous technologies. Business processes are considered to be the appropriate level for analysing the effects of introducing IT in companies. An increased overall organisational performance results from the added improvements in all processes affected by the technology (Melville et al. 2004).

The impact model proposed by Yoo and Lyytinen (2003) for measuring the consequences of ubiquitous computing in networked organizations highlights the interdependence of (1) the capabilities of ubiquitous technologies and the corresponding infrastructure, (2) the existing processes and practices and (3) the availability of complementary resources, e.g. trained staff or new types of factory organization, at creating organizational improvements. The research framework used by Heijden and Valiente (2002) to study the impact of mobile technologies on business process performance illustrates in a similar way that the usage of mobile technologies in business processes creates benefits, which in turn leads to performance improvements. More detail is given by Strassner and Schoch (2003), who specify the functionality of ubiquitous technologies and name identification, monitoring, tracking and notification as the four main drivers for value-creation in processes. The models of the business impact of ubiquitous technologies are closely aligned with more general models of the performance implications of IT. For example, in a meta study by Melville et. al. (2004), the characteristics of business partners and cultural aspects (e.g. the country or industry a company operates in) are identified as additional important determinants for the extent to which a company benefits from IT.

A major shortcoming of the aforementioned models is the lack of detail and consideration of contextual factors. Although categories of factors affecting performance are listed, they are not detailed further. In this respect, the models do not address how and in which business processes value can be created by using ubiquitous technologies. Even if the individual factors affecting performance were known, this would only allow to predict the benefits a specific company could expect and no general statements about the benefits of ubiquitous technologies could be derived.

The theory of task-technology fit (TTF) can be applied to overcome the identified shortcomings. A TTF indicates that the capabilities of a technology match with the requirements arising from tasks or processes (application context), which is a precondition for achieving performance improvements (Goodhue & Thompson 1995). Although the theory of TTF was originally centered on individual users, it has also been applied to organizations as a whole, as their decision about technology usage is based on the similar to that of individuals (Gebauer & Shaw 2004).

A TTF emerges if the functionality of ubiquitous technologies matches with the requirements arising from business processes. As the capabilities of the technology allow to eliminate inefficiencies in the processes and to solve problems that could not at all, or only with inhibitively high costs be solved using traditional approaches, the business process performance is increased.. These relationships are depicted in our research framework in figure 1. As noted above, increased process performance will most likely result in an increased organizational performance, but analyzing this relationship is out of the scope of this study.

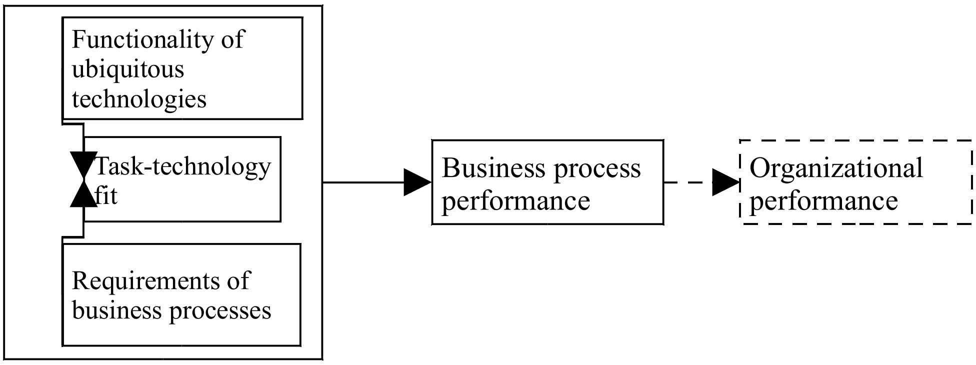

Figure 1. Research framework

2.2 The Functionality of Ubiquitous Technologies

One key element for creating a task-technology fit in the context of our research framework is the functionality of ubiquitous technologies. A first step in understanding the process of value creation is therefore to examine this functionality. We will base our analysis on the functionality of a generic smart item equipped with maximum possible capabilities, regardless of the technology employed. This approach takes into account that functionality depends on the hardware components built into an item rather than on the technology. Potential hardware components include processors, storage, input / output and communication devices, as well as sensors and actuators. Every smart item must at least be able to store data and to communicate. A classification of the functionality of smart items is provided in .table 1.

Table 1. Functionality provided by smart items

Data storage about:	Identity
	Object information
	Relationships
Data capturing of:	Location
	Time
	Sensor measurements
	Presence of objects
Data processing:	Aggregate data
	Recognize events
	Adjust state or behaviour
Communication:	Notify
	Answer queries
Performing actions:	Operate and control
	Generate output

Data storage. Traditionally, data about a companies' business objects is stored in central databases. There is no direct link between an object and the data associated with it. In contrast, ubiquitous technologies enable storing of data directly on an object, thus offering new possibilities to ensure the correctness and timeliness of data. Many ubiquitous computing applications benefit from the possibility to uniquely identify objects. The electronic product code (EPC) is an emerging standard numbering scheme that was designed to serve this purpose (Brock & Cummins 2003). Furthermore, objects can store attributes like weight, colour or manufacturer. If the memory of an item is large enough, whole documents like manuals or repair instructions may be stored. Relationships between objects can be established by storing the ID of corresponding objects.

Data capturing. The object related information described above cannot be captured by a smart item itself. The information needs to be conveyed to the item, e.g. from a business information system (BIS). There is, however, some data that an item can gather autonomously. An item can, for instance, determine its position by using GPS or some other method of calculating its absolute or relative position (Hightower & Boriello 2001). It can determine the current date and time, which is fundamental for building data histories and to capture the entire lifecycle of objects. Smart items may be equipped with physical, chemical, acoustic, or optical sensors, which enables them, e.g., to measure temperatures, monitor the composition of chemicals, take pictures of the environment or record sounds (Beigl et al. 2004). Moreover, the communication device of a smart item can be used as a sensor to detect the presence of other nearby smart items, thus promoting context-awareness and facilitating the cooperative processing of tasks.

Data processing. As the data from smart items shall be integrated in business processes executed by BIS, the problem of handling massive amounts of data arises. Common business software is not prepared for handling large amounts of real-time data and thus needs to be protected from the data flood produced by smart items (Bornhoevd et al. 2004). This is were the processing capabilities of smart items come into play, as they allow to aggregate data to a level that can be handled by centralized systems. For instance, instead of sending every second a temperature value to the BIS, the items can calculate and report average temperature values hourly. The processing capabilities can also be utilized for recognizing events in the real-world and for detecting and analyzing exceptions in data series that must be dealt with. Furthermore, smart items can automatically adapt their state or behaviour to the current context and environmental conditions. For instance, the expiry date of a product can be adjusted to the automatically monitored storage conditions.

Communication. The majority of smart items communicate wirelessly, but wired solutions also exist. Depending on the situation, smart items may communicate with other items, centralized backend systems, mobile devices or global networks. When communicating with BIS, two communication modes can be distinguished. The items either act as mere data capturing and delivery devices, answering queries issued by the central systems, or are more active,, executing parts of the business processes themselves, and notifying the central systems only in case they cannot handle an event autonomously.

Performing actions. Some smart items are not only able to capture and process information (passive items), but rather to change the state of the real world and to perform physical actions (active items) (Fleisch 2001). Embedded systems in particular are designed to operate and control real-world objects, e.g. to change room temperatures or to adjust the speed of a production machine. Actuators enable smart items to perform movements, e.g., in response to changing environmental conditions. Smart items can also interact with human beings: human readable information may be shown on a display and optical or acoustical warnings can be issued.

2.3 Performance Improvements

As the goal of an investment in ubiquitous technologies is to improve business processes and ultimately the performance of a company, it needs to be examined how performance can be assessed. In a specific company, the economic justification for an investment in ubiquitous technologies can be given by employing a standard investment appraisal method, e.g., by calculating the net present value or the payback period. When analyzing reference processes,, more general types of performance improvements must be considered. According to Seibt et al. (1997), the benefits of IT can be attributed to one of the following five categories:

- effectiveness, e.g., boosting productivity,
- efficiency, e.g., improving output quality,
- cycle times, e.g., shortening cycle times or making them more predictable,
- flexibility, e.g., facilitating the change of processes, and
- customer satisfaction.

Moran, McFarlane and Milne (2003) state that the use of ubiquitous technologies may generate performance improvements in any of these categories. Besides improving existing processes, ubiquitous technologies can also be employed to design new and innovative processes. They enable the design of new products and services; they facilitate new forms of collaboration with business partners and may spawn completely new business models. Despite these potentially wider implications, our study will focus on the impact of ubiquitous technologies on existing business processes.

3 Illustrative Cases of Ubiquitous Computing Applications

3.1 Data Collection Methodology

So far, we detailed the functionality smart items provide as well as potential performance improvements. It remains to be explored which problems and requirements fit with the functionality, so that performance improvements can be created. The approach we chose for identifying these requirements is to conduct a series of expert interviews. This is an established qualitative research method commonly used in IS research (Gressgard & Stensaker 2006). Compared to basing our study on cases found in the literature, which often describe idealised business processes, expert interviews offer the possibility to gain a more in-depth understanding of the actual problems companies are facing.

The sixteen experts we interviewed are employees of a standard business software provider. They work as process architects, product managers, and experts for various industry specific applications. Hence they are familiar with a large number of companies and the respective business processes and are thus able to provide information on the most pressing and common problems existing in the industry today. We concentrated on finding experts outside the domain of supply chain management as many ubiquitous computing applications in this area are already well covered and our model shall not be limited to this specific domain. As we aim at developing a general impact model, it would furthermore not have been appropriate to interview representatives of individual organizations, as they have only limited general process knowledge.

We conducted semistructured interviews that were guided by a questionnaire of open-ended questions. The interviewees were first asked about their field of expertise, the business processes they deal with, typical problems that companies executing these processes face and general industry pain points. To narrow down the set of specified problems to those that can potentially be solved with the capabilities of ubiquitous technologies, the experts were familiarized with the functionality of smart items as detailed in chapter 2.2. This step was necessary as the experts had no prior experience with ubiquitous technologies. The processes in which initial application scenarios could be identified were subsequently scrutinized, in particular the process flow, people, objects, geographical locations and information systems involved. This close examination facilitated the discovery of further potential process improvements. The interview participants were eventually asked to estimate the benefits that companies could expect if the improved processes were implemented.

The method chosen implies that the collected ideas do not represent a complete or objective treatment of the phenomenon. It is out of the scope of this study to explore negative aspects of ubiquitous technology usage. Furthermore, it is not intended to collect cutting-edge application scenarios, but rather to identify potential improvements in reference processes from which many companies will benefit.

As some of the interviewees described comparable processes or process steps for different industries, the interview results could be combined to nine application cases. Each of the cases thus describes a comprehensive process, how it is executed today, which problems exist, how and where ubiquitous technologies can be used to improve the process and how the process performance might be affected. Due to spatial limitations, not all cases can be presented here in detail. Therefore, the core idea of six cases will be presented briefly, while three illustrative cases will be described in length

- Case 1: Configuration control exemplified by aircraft maintenance
- Case 2: Asset tracking
- Case 3: Real-time production scheduling

3.2 Case 1: Configuration Control

The configuration control is a software function used in aircraft maintenance that checks whether the configuration emerging after the replacement of aircraft parts is permitted. Performing this control is necessary, as different versions of components as well as components from different manufacturers may be incompatible with each other. Today, the configuration control is one step in a largely paper based process. When required, a service technician will be ordered to dismantle a component of a plane and to install a replacement. He records the

IDs of both components on a sheet of paper, which he passes on to an engineer residing at another location. The engineer will enter the information into the IS and trigger the configuration control. Unfortunately, the service technician will not deliver the maintenance record until he has finished a certain amount of tasks and an engineer is not always present. The entire process may thus take up to two days which means that the configuration control is sometimes performed when a plane has long left the airport. A second problem in this process concerns the dismantled components. They are manually marked as “unserviceable”, e.g. by simply putting a label on them. These labels may be overlooked or fall off, so that components that should be overhauled get mixed up with components already repaired. It thus might happen that an unserviceable component is installed in a plane.

The capabilities of smart items can help to overcome these problems. By utilizing their capability to uniquely identify nearby objects and to communicate with the back-end systems, a solution can be designed in which the BIS is notified in real-time about any changes of the aircraft configuration. For instance, all critical parts of a plane could be equipped with RFID tags as well as the service technicians with mobile devices. The mobile devices can then immediately transmit the ID of the dismantled as well as of the new component to the backend system, which performs the configuration control and transmits the result back to the mobile device. In a more sophisticated scenario, the components of a plane could communicate with each other in order to determine autonomously whether the current configuration of the plane is permitted. Furthermore, the RFID tags on the components can store the state of a component (serviceable / unserviceable). If somebody tries to install a part marked as unserviceable in a plane, a warning can be issued.

When optimizing the process by using ubiquitous technologies, the hand-over of information recorded on paper is avoided, which in consequence reduces labour costs. The process will run faster, as waiting times are eliminated. However, it is most important in aviation, that the likelihood of errors is reduced, as errors may have dramatic consequences. For instance the consequences of an emergency landing that was caused by technical failures due to incompatible components are severe. Errors in safety critical domains can entail high costs and may severely damage the image of a company. Companies operating in these domains will thus generally be willing to invest in innovative technologies if they promise to boost safety.

3.2 Case 2:Asset Tracking

Information about the assets a company possesses as well as of the location they are in is in many cases stored in the database of an asset management system. The term “asset” refers to all kinds of technical objects, ranging from laptops and forklifts to entire production plants. The locations of assets are stored in a tree-like structure called functional location which represents e.g. buildings, floors and rooms. Today, the location of an asset is entered manually into the system or this is facilitated by the use of barcodes. People tend to forget to assign locations to assets, they enter wrong data or assets are moved and the corresponding location is not updated. This results in inaccurate inventory levels, people spending much time looking for assets, difficulties in assigning asset costs to departments, and the inability to maintain and service assets as they are not found. An additional problem affecting mobile assets such as notebooks or beamers is that they are frequently stolen from companies. This means that not only the location of assets is uncertain, but sometimes also their mere presence within the boundaries of a company.

By employing ubiquitous technologies, an infrastructure can be created that allows to identify and localize each asset at any time and to check for its presence. For that purpose, it is necessary to turn the assets into smart items, e.g. by putting RFID tags on them. RFID readers can then be installed in the doors, rooms or corridors of the buildings. By propagating asset data to the back-end systems, e.g. every time an asset is moved, it can be ensured that the correct asset location is maintained in the database. Furthermore, by querying the IDs and object types of all assets, the manual stocktaking carried out today can be automated or at least be facilitated. When the tracking of assets is enabled, it can also be utilized to prevent theft. For instance, the exits of a building can check whether assets passing through them are permitted to leave the building and issue an alarm if necessary.

Optimizing the asset management will raise employee productivity and cut down labour costs since people spend less time looking for assets, manually assigning assets to functional locations, revising wrong data in the system, and stocktaking.

An automated stocktaking solution will furthermore avoid the halt of operations often associated with stocktaking today. The decline in asset theft will lower the expenses for replacing stolen assets. Making the number and location of assets in more transparent will prevent the unnecessary replacement of undetected or hidden assets that sometimes happens today.

3.3 Case 3: Real-Time Production Scheduling

An enterprise manufacturing solution determines the optimum production schedule for a given set of orders, observing a multitude of constraints pertaining e.g. to the number of production machines or the available preliminary products. When the optimum schedule for a predetermined time period has been established, it is fixed and production will start according to it. This means that the production process is quite inflexible and often suboptimal, as no data about the actual state of the shop floor is used to optimize the schedule once production has started. Besides the inability of many enterprise systems to handle large amounts of real-time data, the lack of available data is a problem in itself. Usually, no information about the location and amount of work in progress, the state of machines, the actual availability of preliminary products, or the position of congestions on the shop floor is reported back to the manufacturing system, let alone incorporated in the calculation of an updated production schedule. Thus, if an unexpected event happens, such as the breakdown of a machine, the schedule cannot be immediately adjusted. Although some companies use automatic or manual production data acquisition systems, this is no real improvement as the data captured is only used for the subsequent generation of reports on how the completed production process performed.

Ubiquitous technologies can be used to constantly monitor the state of all objects on the shop floor, to aggregate the huge amounts of data, and to inform the manufacturing systems if needed. As the position of smart items can be determined, all preliminary and finished products, containers, transport devices and people moving on the shop floor can be tracked. The condition and state of machines and products can be measured by sensors and the back-end systems can be informed about it, in particular if rules determining the production process are violated. Compared to the data captured by today’s production data acquisition systems, the level of detail and comprehensiveness of the data is extended, e.g. by capturing the processing times and conditions of individual objects. The detailed information provided by the smart items can then be used by the manufacturing systems to optimize the production schedule based on the actual situation.

As manual or semi automated production data acquisition becomes obsolete with the introduction of ubiquitous computing applications, labour costs will be reduced. However, these savings are negligible compared to what can be achieved by optimizing production scheduling. Significant increases in productivity can be expected when better schedules are calculated. Companies will be able to better predict the completion times of their products and to issue more reliable delivery dates. Moreover, as the production conditions of individual products can be tracked, companies will be able to prove the compliance to regulations and the absence of errors during production, which may help to reduce penalties.

3.5 Cases 4-9: Further Applications

Based on the expert interviews, six more application cases could be identified. As the subsequent data analysis is based on all nine application scenarios, the remaining cases are sketched here briefly:

- Automated updating of the installed base: Ubiquitous technologies can be employed to ensure that information about the configuration and structure of objects is kept up-to-date in the IS. For this purpose, the individual parts of objects must be tagged and version information be stored on the tag. Thus, the handling of configuration information during manufacturing, maintenance and when objects are transferred to a third party are improved.
- Condition based maintenance: In this scenario, information about the condition of an asset is captured by sensors and its daily operations are monitored. This information is used to predict the point in time when the next maintenance is needed. Preventive maintenance helps to reduce the downtime of assets and thus increases productivity.
- Mobile asset maintenance: Ubiquitous technologies allow to improve the mandatory maintenance of fire vents at airports. RFID tags are attached to the vents and the service technicians are supplied with mobile devices. When a technician approaches a vent, the tag and the mobile device communicate with each other which ensures that the service is performed

correctly. The former error-prone paper-based process is replaced and the storage of large amounts of maintenance documents can be omitted.

- Optimizing the production schedule by incorporating additional data: In this scenario, additional information about the state of the preliminary products used for manufacturing, e.g., their temperature, viscosity, expiry date or their position in the warehouse is used to optimize the initial production schedule calculated by the system.
- Tool management: Ubiquitous technologies can help to predict when tools used on the shop floor, such as extrusion rams, need to be replaced due to deterioration. As tools consist of various components of which each has a different life span and the life span depends on the attributes of the handled product (e.g. soft/hardened steel), tagging of the tool components and the processed objects can help to predict the replacement time. When replacement tools are supplied in time, machine downtime is minimized.
- Picking and final checking in warehouses: It needs to be checked whether the picked goods match the placed orders. With the help of ubiquitous technologies, the identity and type of objects can be queried and transmitted electronically. This capability can be used to facilitate the picking process and check whether the content of picking boxes or containers is complete and correct.

4 Data Analysis and Implications

4.1 Approach

The underlying aim of the data collection was to find the specific problems that fit to the functionality of ubiquitous technologies and thus create a TTF. To identify these problems, each of the application scenarios was split up into atomic pairs of problems and solutions (applications). This becomes necessary as, e.g., the configuration control process consists of two essentially different applications of ubiquitous technologies: on the one hand, the configuration control itself is improved; on the other hand, the false classification of dismantled components is avoided. By comparing problem-solution pairs, distinct patterns could be found that allowed to classify the problems into several distinct problem types. For each of the identified applications of ubiquitous technologies, the corresponding problem classes and the functionality needed to solve the problem in that specific case are illustrated in table 2.

Table 2. Problem classes and matching functionalities revealed in the applications.

Functionality	Storage			Capturing				Processing			Communication		Action		
Cases and applications	ID	Object data	Relationship	Location	Sensor	Presence	Time	Aggregation	Event Detection	Adjustment	Notification	Query	Control	Output	Problem Type
Case1: Configuration control															
Performing the check	X		X			X			X		X			X	Delayed reaction Manual data capture Consistency check
Handling of dismantled components		X	X			X			X			X		X	Consistency check
Case 2: Asset tracking															
Document location	X			X		X			X		X				Incorrect data Manual data capture
Stocktaking	X											X			Incorrect data Manual data capture
Prevent theft by documenting ownership	X	X				X	X		X			X			Data cannot be gathered efficiently Missing evidence
Prevent theft by blocking doors		X				X			X		X	X	X		Consistency check
Case 3: Real-time optimization of production schedules															
Work in progress tracking	X			X		X	X	X	X		X				Manual data capture Data cannot be gathered efficiently Missing evidence
Improved manufacturing	X	X		X		X	X	X	X		X		X		Delayed reaction
Employee safety and product checking	X		X			X			X		X	X		X	Consistency check
Case 4: Update installed base															
Creation	X	X										X			Incorrect data
Transfer	X	X										X			Manual data capture
Configuration change	X	X				X			X		X				Incorrect data Manual data capture
Support of technician	X	X										X		X	Data required on site
Case 5: Condition based maintenance															
Asset monitoring	X				X			X	X		X				Delayed Reaction Manual data capture Data cannot be gathered efficiently
Support of service technician		X			X			X	X			X		X	Data required on site
Case 6: Mobile asset															

Functionality	Storage			Capturing				Processing			Communication		Action		
Cases and applications	ID	Object data	Relationship	Location	Sensor	Presence	Time	Aggregation	Event Detection	Adjustment	Notification	Query	Control	Output	Problem Type
maintenance															
Performing maintenance	X					X	X		X						Manual data capture Missing evidence
Case 7: Detailed production scheduling															
Storage location of materials	X			X								X			Data cannot be gathered efficiently
Optimize schedule with regard to expiry dates	X	X										X			Data cannot be gathered efficiently
State of objects	X				X							X			Data cannot be gathered efficiently
Case 8: Tool management															
Determination of replacement time	X	X				X			X	X	X	X			Data cannot be gathered efficiently
Case 9: Picking and final checking															
Picking	X		X			X			X		X			X	Manual data capture Consistency check

Each class of problems can be solved with one ore more specific combinations of capabilities of ubiquitous technologies. This relationship was analyzed for all problem types as showcased in table 3.. In this example, which covers two applications, a service technician is on site either for performing condition based maintenance or for replacing components and needs up to date and correct information about the object he has to service (ID, attributes, aggregated sensor measurements), which is not available to him today. In the improved process, he will be able to query the object directly, and the data will be sent to his mobile device or displayed on the object itself.

Functionality	Data storage			Data capturing				Data processing			Communication		Action		
Application	ID	Attributes	Relationships	Position	Sensor Data	Presence	Time	Aggregation	Detect Events	Adjustment	Notifications	Query	Control	Output	Problem / Requirement
Support of service technicians on site when changing components	X	X										X		X	Data required on site
Support of service technicians on site when performing condition based maintenance		X			X			X				X		X	Data required on site

Table 3. How ubiquitous technologies provide object information on site.

The comparison of the application scenarios revealed another pattern. We were able to identify four factors that do not refer to problems that may be solved by ubiquitous technologies, but rather hint at the extent of the performance improvements that can be expected. These four factors along with the seven identified problem types are detailed in the next section.

4.2. The structure of value-creating ubiquitous computing applications

The first type of problem that may be solved with ubiquitous technologies is the storage of **incorrect information about the state of the real world** in IS. This information includes object attributes such as temperature, location or configuration, but also aggregated values such as inventory levels. The reason for a discrepancy between the actual state of the world and the state represented in the IS is the media break between the real world and the virtual world (Fleisch 2001). As the state of the real world is not automatically transmitted to the IS, a manual data entry is necessary which may entail errors and omissions. Problems surface when the false data is used to take decisions, which are in consequence wrong or suboptimal and generate avoidable costs. In terms of requirements, this means that the data utilized in a process needs to be correct or otherwise the process performance will decline. There are two ways in which ubiquitous technologies can contribute to overcoming this problem. First, the backend system can query the smart items about the state of the real world before taking a decision. Second, smart items can constantly monitor the state of the real world and, as soon as relevant changes occur, notify the central systems. This ensures that the decisions taken are based on correct input values.

The next problem that can be tackled by using ubiquitous technologies is a **delayed reaction to events in the real world**. A delay may be caused by waiting times in manual processes or by a missing systematic monitoring of the real world, e.g. when people discover urgent problems by mere chance. In the application scenarios, a delayed reaction emerged in the configuration control process. Other examples are a production machine that is not repaired or a tool that is not replaced immediately, because it takes too long to detect the error and to inform the responsible person about the event. In this case, the decisive capability of smart items is their ability to notify the backend systems nearly in

real-time about events in the real world that need their attention. Beyond that, it is also possible to design processes in which the central systems are no longer needed. Smart items can also detect important events and react to them autonomously and immediately, e.g. by issuing a warning when the rules specifying the configuration of an airplane are violated.
Ubiquitous technologies can be employed when **information is required on site,** e.g. at the place where an object resides. This may be the case when no IS is available, e.g., in warehouses or hangars, but also when access rights for retrieving information are missing, e.g., if objects are transferred to another company. Smart items are well suited for solving this kind of problem because they carry information about themselves with them, all the time and everywhere they go, and this information can be retrieved electronically. Thus, smart items can meet all local information needs. The immediate availability of information also facilitates the exchange of products and data between organizations.

If companies want or need to (e.g. because they must comply with regulations) **give evidence about the lifecycle of objects and achieve accountability**, they can do so by using ubiquitous technologies. Compared to today's methods of monitoring the lifecycle of objects, e.g. processes relying heavily on paperwork, ubiquitous technologies offer a much higher degree of certainty. As the physical and the information processing component of a smart item are continuously connected, the entire lifecycle of an object can be recorded, e.g., changes in its state, actions taken, or objects the item interacted with. This allows companies to prove that assets were serviced regularly, that the production process was carried out correctly or that they manufactured a certain product.

In most of the examined processes, an inefficient **manual or semi-automated (using barcodes) data entry and data capturing** was performed. Process steps carried out manually may not only cause errors and delays, but they also produce labour costs. Many paper-based and manual processes can be automated by using ubiquitous technologies, as long as the process deals with real-world objects. Smart items can capture the data needed and send all relevant information automatically to the target systems. Thus, manual data gathering and data entry are avoided.

Ubiquitous technologies can enhance scenarios in which the **state of the real world regarding objects and their attributes is not checked adequately**. A correct state of the real world may depend on the presence or absence of objects or of certain combinations of objects, on the completeness of a defined set of objects, or on the presence, absence or specific combination of certain attributes of objects. When it needs to be checked whether deliveries are complete and their composition correct, whether a worker has the required training to operate a machine, whether a component is serviceable or whether an asset is authorized to leave a building, smart items can be of use. Today, these checks are either performed manually, sporadic, or not at all. Ubiquitous technologies not only allow to perform these checks automatically, but they can also ensure that the rules pertaining to a correct world state are observed continuously. In case the rules are violated, a warning can be issued or actions triggered that aim at restoring a correct state.

Quite often companies are aware of the data input needed to improve the decision quality, but with the available technologies, **this information about the state of the real world cannot be gathered efficiently** enough. In many cases, a way of gathering the input using conventional means can be envisioned, but implementing it would be too costly compared to the benefits of an improved decision quality. As smart items are cheap and efficient data gathering devices, they can be used to extend the monitoring of the real world: individual objects can be controlled instead of lots, more attributes and values can be stored, and more objects can be incorporated into IS. While today only few expensive or mission critical objects are connected to the backend systems scheduling preventive maintenance, many more objects can be hooked up when ubiquitous technologies are used to capture and aggregate data before transmitting it.

The four factors that hint at the extent of potential savings and indicate that companies might be willing to invest in ubiquitous technologies as the cost-benefit ratio is favourable are: a high object price, safety critical operations, the need to comply with regulations and high costs of asset downtime. Ubiquitous technologies can help to prevent objects from being damaged, stolen or getting lost because they enable a close monitoring, tracking and checking of objects. The **higher the object price** is, the higher are the costs for replacing an asset and the bigger is the incentive for companies to invest in ubiquitous technologies to avoid these costs.

When dealing with dangerous objects or processes, the costs of errors are potentially high. Furthermore, when performing **safety critical operations,** people might get injured and an incident may have devastating consequences for the image of a company. As ubiquitous technologies help to prevent errors by replacing human labour and by checking actions performed by humans, companies conducting safety critical operations will be willing to invest in promising technologies.

Ubiquitous technologies can help companies in various ways to ensure and to prove that they **comply with regulations** that are determined e.g. by public authorities. Today, many companies spend an enormous effort for complying with regulations by employing conventional means. Ubiquitous technologies offer in many cases a cheaper and more reliable alternative.

Ubiquitous technologies can be employed to maximize the uptime of assets and to increase their productivity. This can be achieved by enabling preventive maintenance, by optimizing production schedules or by quickly restoring normal operations in case of unexpected events. The **higher the costs of asset downtime** are, the more willing will companies be to invest in ubiquitous technologies.

Figure 3 summarizes our findings and shows how the factors presented in this section fit into the research framework. The model illustrates how the functionality of ubiquitous technologies in conjunction with a specific set of problems creates a TTF, which in turn affects the process performance (only examples are given) and organizational performance. Furthermore, the initial model was extended to comprise the factors influencing the cost-value ratio.

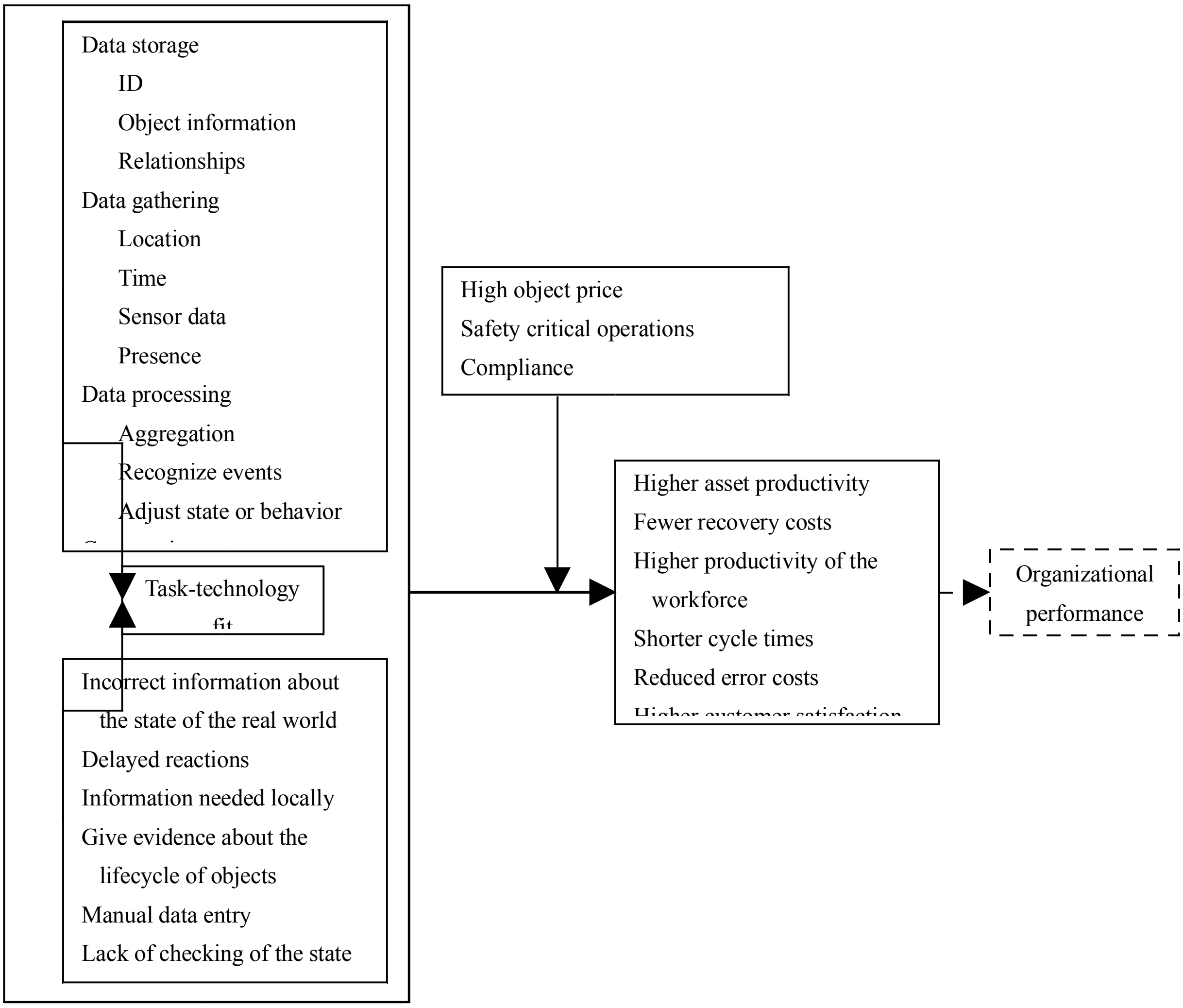

Figure 2. How ubiquitous technologies create business value.

4.3 Practical Application

The results of our study can easily be applied to help companies identify applications of ubiquitous technologies that suit their specific needs, because the problem types also act as indicators for potential process improvements. These indicators were used to derive a questionnaire targeted at identifying potential application areas. After discovering suitable processes, it remains to be determined by each company whether the envisioned process optimization is technically and economically feasible. Potential questions include:

- In which cases is the state of the real world not reflected correctly in the IS? In which processes does that lead to wrong decisions and with which consequences?
- In which processes are reactions to events in the real world delayed? For which decisions do you need real-time data?

- In which processes have employees no access to IS or work in an offline scenario, but need object information?
- Which measures do you employ to give evidence about the lifecycle of objects? In which situations do you need to give hard evidence?
- In which processes is object information entered, captured or transmitted manually? Where do media breaks occur? Which processes dealing with objects are paper-based?
- In which cases is the completeness, composition, absence or presence of real world objects checked? In which cases are documents accompanying an object checked? In which processes is the flow determined by object attributes?
- In which processes can the decision quality be improved by more and better information about the state of the real world? In which cases are objects not monitored electronically because this is too costly?
- In which processes and for which objects emerge high replacement costs due to loss or damage?
- In which processes must the safety of operations be guaranteed? In which cases may errors have severe consequences for the safety of people or objects?
- In which areas must regulations be observed? What has to be documented for public authorities?
- For which objects is a period in which they are unproductive extremely costly? In which processes do objects have to be continuously available and ready to operate?

5 Summary and Outlook

We presented how ubiquitous technologies can contribute to an increased organizational performance and presented a questionnaire that allows to apply these findings to identify value-creating ubiquitous computing applications. The approach we chose is unique in two aspects: First, we did not limit the study to a specific domain, but rather examined generic reference processes. Second, our study is based on an appropriate theoretical foundation. We applied the theory of task-technology fit to link the functionality of ubiquitous technologies to organizational performance. Based on a series of expert interviews, several types of problems that can be solved by using this functionality were identified and these problem areas were transformed into a set of questions that help companies to quickly identify ubiquitous computing applications that meet their needs. We also proposed a detailed model of the business impact of ubiquitous technologies.

The identified problem types are comprehensive, but neither complete nor entirely disjunctive. By examining more case studies from literature or interviews, the identified problem types should be verified and further problem classes could be determined. The proposed method for identifying value-creating applications must be evaluated in real companies. If a company expresses interest in using ubiquitous technologies, the technical and economical feasibility need to be assessed, i.e. whether the benefits outweigh the present costs of buying, installing and maintaining an application. As a next step, it should be possible to establish a quantitative model of the impact of ubiquitous technologies and to develop a business case framework, if a sufficient amount of real-world applications has been implemented and analyzed.

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