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Business Impact of Pervasive Technologies: opportunities and Risks

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Abstract

Despite heavy investment in integrated information systems, many business problems still prevail due to a lack of integration between the real and virtual world. Low data granularity presently limits enterprise computing. In order to solve these problems, data granularity needs to be increased and the digital management control loop must to be closed. Pervasive Computing, including automatic identification, is the technological enabler. Once closed digital management control loops are in place and generating high data granularity, incremental process changes such as an automatic quality check, enhance the overall efficiency of controlling intensive processes. Object value logging and embedded services are examples of more radical changes, which not only affect processes, but also business models. However, although the pervasive technology-based development road map of future enterprise computing systems seems to be straightforward, various risks and challenges have the potential to strongly influence the technology adoption path.

1. Limitations of Today's Enterprise Computing Systems

Throughout its history, enterprise computing has consistently followed one underlying goal. Computer systems supporting isolated enterprise functions such as controlling, finance, sales, or production, were established for the same reason as enterprise resource planning systems that support cross-functional business processes within companies, or even e-business systems enabling cross-company processes. Enterprise computing systems have always been formulated to deliver decisionrelevant data to managers as rapidly as possible. For instance, SAP named its famous packaged-enterprise software R/2 and later R/3 where R stands for real time. In real time information systems, all information generated at a point of creation (POC) is immediately made available to all points of action (POA) that leverage the information for better decision-making (Fleisch and Österle 2003). In business environments, better decisions should eventually result in greater revenues and margins.

Integration is the most important means of achieving real-time systems. Integrated systems consistently try to avoid media breaks, which would require that, in order to be processed or transported, the very same piece of information needs to be written with and by different media (e .g., hard disk, email, fax paper). Media break resolution usually requires new data interpretation and data entry. Both are likely to be performed by skilled or semi-skilled workers. Thus, media breaks between POC and POA are time consuming, error-prone, and ultimately rather costly. Enterprise resource planning systems are designed to avoid media breaks within a company's borders, basically by managing all enterprise data in a single database. E-business systems minimize media breaks by hard and soft wiring supplier and customer information systems via Internet-based business collaboration infrastructures, such as market places or Web services.

Although existing information systems already solve many integration problems, the vision of the real time company will not be achieved for some time to come. Businesses still suffer from a lack of useful data, which causes inefficiency. For example, consumer goods and retail companies are currently unable to effectively manage their out of stock, shelf life time, cool-chain, theft, and counterfeit problems. If a retail company knew exactly which products are on the shelf and which are in the warehouse, it could reduce its out-of-stock problems considerably (Gruen et al. 2002; Alexander *et al.* 2002). Why don't retail chains simply collect the corresponding data or derive it from their bar code–based checkout systems? The answer to this question is straightforward and in line with the integration problem: based on today's technology, full data collection, which can be regarded as the integration of information systems with the physical world, is expensive.

Thus, companies developed data gathering and processing methods that support low data granularity. For instance, because collecting reliable inventory information is time consuming and expensive, companies take stock only once a year. Alternatively, because it is too costly to check the completeness of each order received or shipment to a customer against the data in the information system, companies check the real against the virtual data on a statistical basis.

The current high cost of integrating the real with the virtual world results in decisions at the POA that are based on low granularity information. Managers at the POA rely heavily on statistics based on historical data.

2. The Contribution of Pervasive Computing

Pervasive Computing has the potential to reduce the cost of integrating the physical world with information systems (Figure 1). The POC employs sensors that automatically sense data form its environment, e.g., radio frequency identification (RFID) readers that sense the identification numbers of objects within their reading range. On the POA, actuators might translate the data from different POC automatically into value, for example, by sending an out-of-stock notification to another information system or an employee. Once POC and POA can handle data automatically, human intervention, for example, for data entry, is not necessarily required. And when humans are out of the computing loop (Tennehouse 2000; Wired 1999), data can be gathered, processed, and distributed in real time.

With the price of sensors and actuators decreasing, conventional data entry and data leveraging methods are substituted by Pervasive Computing technologies. In addition to the substitution effect, an elasticity effect can be observed: Additional sensors and actuators are employed where companies can create value from a higher data granularity, that is, where the benefits from higher granularity exceed the cost of higher granularity.

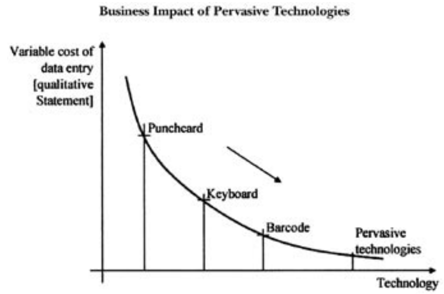

Fig. 1: Pervasive Computing reduces cost of integrating the physical world.

2.1 Increasing Data Granularity

Data granularity can be described in four dimensions. The first dimension is dependent on the time scale. Time granularity is low when, as in the inventory check example, the data entry component of a business case only allows the occasional reality check. Time granularity is high, if a sensor technology's marginal costs enable a justification that favors ongoing checks with the physical environment (Figure 2). Information systems with such a high time granularity do not depend on the stochastics of the time scale — they are always operational. In principle, they can collect a complete history of a physical instance and detect real-world events in real time.

The next two granularity dimensions depend on the physical objects in order to be integrated. One dimension describes the type of object. With the advent of Pervasive Computing technologies, the objects that can be integrated with a positive business case tend to become smaller and less valuable.Ajustification now for tagging reusable transport containers very likely prevails. With the mandate of Wal-Mart, the U.S. Department of Defense, and Metro, the tagging of pallets and cartons is likely to reach a critical mass for writing a sound business case (RFID Journal 2003; Metro Group 2004; Department of Defense 2003). In some industries, for example, in the textile industry, which deals with high-value and highly individual products, even item tagging starts to pay off (Kaufhof 2003).

The third granularity dimension describes how many physical objects of a class (*e.g.*, boxes) are integrated. As it becomes less expensive to integrate physical objects with the digital world, more objects (instances of boxes) within one object class (all boxes) will be equipped with Pervasive Computing technology. As a consequence, the number of objects per class granularity rises. For instance, if a mail order company equips 5% of its video camera boxes with RFID-Tags, the object granularity is rather low, compared to the maximum of 100%. However, in various situations, such as detecting where typical high-value shipments get delayed, lost, or stolen, a small object granularity might make sense.

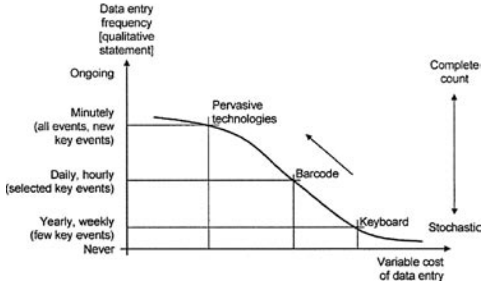

Fig. 2: Pervasive Computing increases time granularity.

The fourth dimension of data granularity likely to be increased by Pervasive Computing technology is the variety of data to be collected automatically. At minimum, the integration of physical objects requires a unique identifier of the object class or the object instance. Twenty-five years ago EAN/UCC started providing the retail business with a unique class identifier. In 2003, the Auto-ID Center proposed the electronic product code, a unique identifier at instance level (Ashton and Sarma 2003). Advanced Pervasive Computing applications, for example, in the automotive and high-tech industry, already collect additional object-related data such as quality management data, the forthcoming production stages, customer name, or target configuration. Adding new sensors allows the integration of data from the immediate environment of the objects (Figure 3).

Pervasive Computing reduces the marginal cost of integrating the real with the virtual world. It thus enables information systems to collect more detailed data at the POC and eventually allows managers and machines at the POA to base and implement decisions on high granularity real-time information.

2.2 Closing the Digital Management Control Loop

The integration of the real world with the virtual world enables the digital management control loop to be closed (Figure 4). In an ideal real-time business, information becomes available instantaneously at the point of use or POA as and when it is generated at the POC. Both the POC and POA can be assigned to different organization units and thus necessitate intra-organizational and inter-organizational information flows.

As can be seen from the example of retail trade, a large number of POCs and POAs can be identified in the supply chain—always at the precise moment when information is created or used. The choice of POC and POA will depend on the areas to be controlled—referred to in measuring and control technology as the “control loop”. This might involve individual tasks, internal and inter-organizational processes, company divisions, value chains, and company networks.

These are affected continually by disturbance variables such as machine failures, shrinkage, quality and demand fluctuations, which influence the controlled variables (actual values), such as process or company performance indicators, and required real-time management. At the POA, the decision-maker (controller) compares target values (command variables) with actual values and defines measures (manipulated variables) aimed at influencing the control loop, so that the controlled variables meet the targets.

Every interruption in the control loop leads to delays and additional disturbance variables. Processes, businesses, and business networks then cannot be managed in real time. Pervasive Computing technologies, particularly automatic identification, sensor, and actuator technology, are the technical foundation for the digitization and automation of POC and POA. They are essential prerequisites for creating digital management control loops.

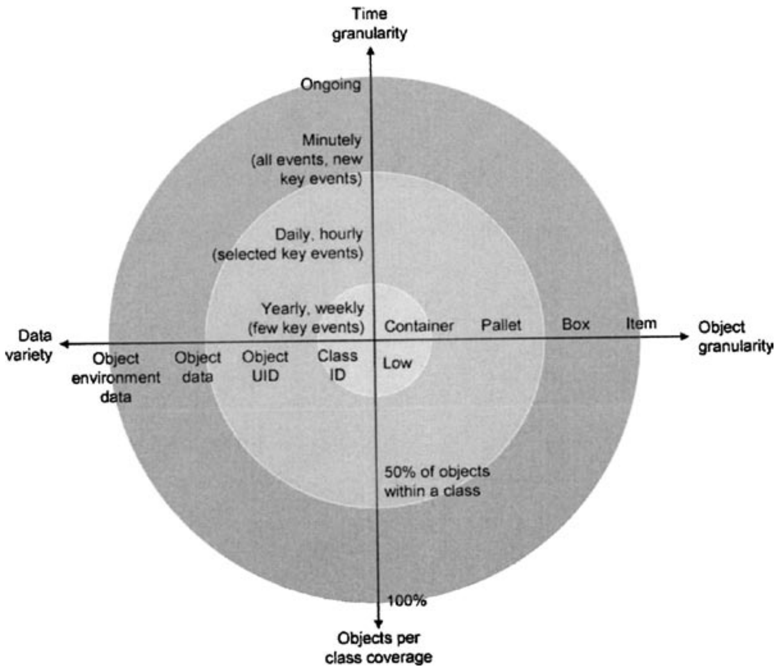

Fig. 3: How Pervasive Computing changes the data granularity in business applications.

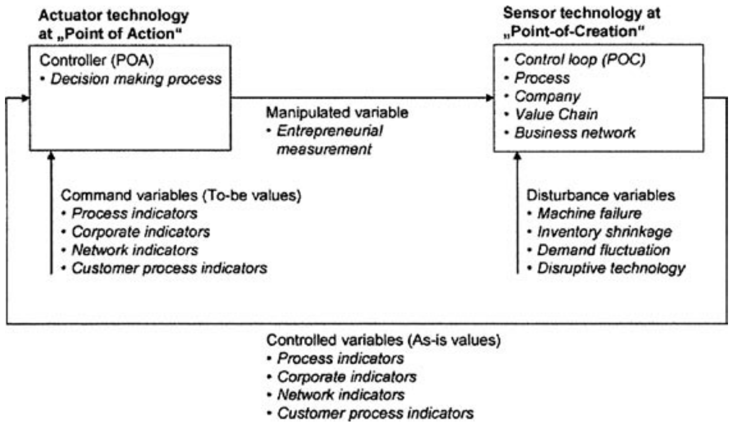

Fig. 4: Digital management control loop.

3. Opportunities: Changing Controlling Intensive Processes

Developing the arguments from the previous section, we conclude that Pervasive Computing technologies will primarily be used in controlling intensive processes, that is, processes that require high data granularity. Auto-ID technologies, embedded systems, and sensor networks will not be implemented if the already familiar and costefficient statistical methods provide sufficient data granularity and if there is no value in closing the digital management control loop.

3.1 Incremental Versus Radical Changes

The change in controlling intensive processes can be divided into two classes. Class-one groups existing processes with a high controlling intensity by nature or law. Class-one processes such as quality assurance need to be tightly controlled irrespective of whether there are Pervasive Computing technologies. New technology only makes those processes faster, more accurate, reliable, and cost efficient. It creates only an incremental change, not a substantial one. Most of the current RFID projects deal with class-one processes changes. They reduce failure rates, shrinkage, operating stock, and enhance on-time delivery, shipment quality, and so forth[1]. Overall, class-one process changes provide value by modifying the way companies manage their resources (how), but they do not change companies’ business models (what).

Class-two changes use the advent of high data granularity as a basis for new business models. In class-two changes, companies do not question how they could improve their current processes with Pervasive Computing technology. Instead, they investigate which new services they could offer to their customers, given that they can manage control-intensive processes at reasonably low cost. Whereas class-one changes seek for incremental deltas, which in the short term typically affect only a company’s efficiency, class-two changes strive for more radical innovations that affect customer relations, services, and revenues models (Venkatraman 1994).

3.2 Autmatic Quality Checks

Most currently discussed or implemented business scenarios that employ pervasive technologies are class-one changes on the conceptual basis of an automated quality check. In a typical supply chain, quality checks are performed before, during, and/or after critical process steps such as change of ownership or events

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[1] For a detailed investigation of incremental process changes based on RFID technology, see Fleisch and Dierkes (2003).

with the potential to create and destroy value. In a typical quality check, a worker measures a current value in the real world and checks it against upper and/or lower limits of previously defined to-be values that he finds in the computer system. For instance, a worker in the shipment department of a warehouse opens a box with textiles ready for shipping to check whether the contents match the list from the warehouse management system. This manually performed quality check task is very time consuming, costly, and error-prone. For that reason, an average textile company checks only a small percentage of its shipments. It thus relies heavily on stochastics and has to face relatively high costs resulting from incorrect deliveries. A textile supply chain RFID solution such as that currently used by Gerry Weber and Kaufhof (Kaufhof 2003) enables the automation of those quality checks. It reduces the checking cost to the point where it is efficient to run 100% checks.

By introducing Pervasive Computing–based quality checks, the number of checks and thus the supply chain quality will rise. Also, under certain preconditions (cost of failure is high and declines with adding granularity, whereas cost of manual quality checks increases strongly with additional data granularity), it is likely that the sum of checking and failure costs declines. This could explain why companies such as Wal-Mart and Metro strongly invest in the development of RFID solutions. However, future research has to verify the hypothetical cost curves (Figure 5).

3.3 Value Logging: Usage-Based Pricing and Accountability

High data granularity at low cost ultimately allows the ongoing "live" collection and storage of a tagged object, especially its business-relevant data. For instance, car insurance providers, in agreement with the customer, may tag customers' cars with GPS sensors and track the cars' routes (Progressive Insurance 2000; Litman 2002).

The combination of the data with business-value drivers facilitates real-data-based business agreements between a vendor and its customer. This would allow vendor and customer to negotiate a price that is not based on average costs over all customers, but on the individual costs of the customer in question (Figure 6). A large part of the statistics would be replaced by real-world data.

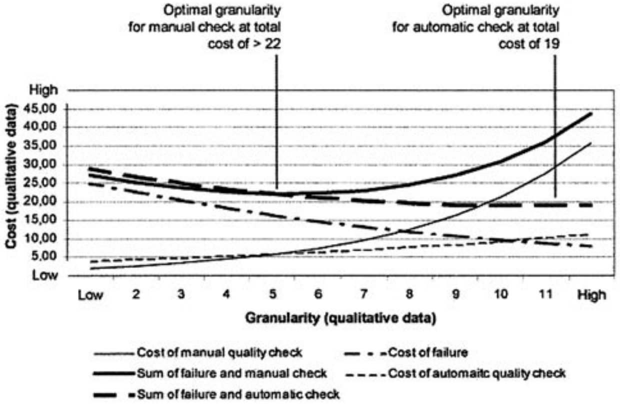

Fig. 5: Cost of manual versus automatic quality checks.

Once a company knows which events drive or destroy value and is able to costefficiently collect theses events, it can initiate a class-two change by transforming its business model from selling services at a fixed price to usage-based pricing. Car insurance companies would then collect the driving patterns of their customers and recalculate the car insurance price each month, based on driving by night or day, highway or in town, good or bad neighborhood, weather conditions, and so on.

Usage-based pricing models can provide substantial benefits for customers and vendors. Whereas service companies can base their pricing on mutually trusted usage information, product companies could ultimately become lucrative service companies. They could stop selling products such as drilling machines. Instead, Pervasive Computing might enable them to sell services such as drilling holes or managing the entire range of machinery at a construction site.

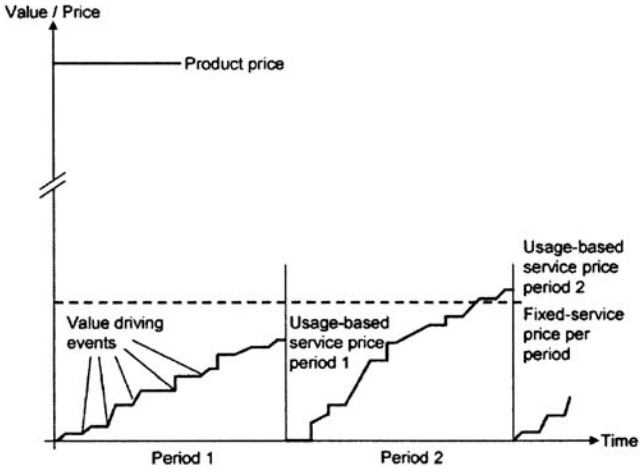

Fig. 6: Value logging enables usage-based pricing.

Another function, with all its opportunities and risks, that value-logging could provide is evidence of accountability. The logging of highly granular data could answer questions such as: Who ruined the engine in the new rental car? Who gave the patient the wrong medicine? Who replaced the bumper with the defective counterfeit product causing a mass collision on the highway? Who let the frozen oysters warm up causing fish poisoning or who used the wrong sequence of chemical infusion into the reactor causing an explosion? Who is accountable for value added or lost? Who should pay for the consequences? Reliable high-granularity data might enable and force companies to change their customer and vendor contracts in order to cover all accountability cases. Again, Pervasive Computing removes stochastics and replaces it with highly individual real-world data. Whereas it definitely makes technical sense to enforce accountability in many cases, in other cases, such as where the effects of chaotic chain reactions are applied, the transparent history of objects has clear limitations, if not serious disadvantages.

3.4 Embedded Services: Product and Service Bundling

From the research on industrial services, we know that product companies that also offer product-related services, on average earn more than companies that stick to product selling (Friedli and Gebauer 2004; Wise and Baumgartner 1999). The reasons for this trend are quite clear: On the one hand, products are becoming commodities so that the profit margins decline. In addition, product companies provide an increasing number of free product-related services to the customer, which reduces the margin even more. On the other hand, the customer is willing to outsource many of the coordination tasks to services providers. The service business itself is quite appealing, because of its financial, marketing, and strategic opportunities. The substantial potential revenue, higher margins, and the fact that services are a more stable source of revenue, represent the financial benefit. Marketing opportunities can be understood in this context as the use of services to sell more products. Finally, there are strategic arguments such as competitive strategy based on services. By virtue of being more labor dependent, services are much more difficult to imitate than products. Services are thus becoming a sustainable source of competitive advantage. So many product companies are currently attempting to transform themselves into companies selling both products and product-related services.

Pervasive Computing clearly offers an opportunity for manufacturing companies to link products with ongoing high-margin services (Fleisch and Dierkes 2003). A tagging or embedded system never creates value itself. It is always the service that generates value. Pervasive technology links objects with value-adding services.

Companies are planning to add minicomputers to their products, because they want to sell value-added services. For instance, Chep, the world's largest palette and container pooling service provider, plans to tag its more than 250 Mio reusable palettes in order to offer its customers not only products, but also logistical information services.

Product companies claim that integrated services can be engineered more carefully and thus delivered more cost efficiently. Therefore they may engineer printers, lighting systems, video projectors, and so on, that can "order" their disposal refills and spare parts automatically at the right time at the lowest possible total cost of ownership via Pervasive Computing technology.On the other hand, customers may claim that the products could order refills too early, generating high maintenance costs, or that the free choice of service provider is limited due to strong technology-based service lock-in. To overcome those potential conflicts of interest, the information generated by Pervasive Computing–enabled products must be made transparent, reliable, and accessible to everyone — even to competitors in the service business. Only transparency and free service-provider choice will enable customers and vendors to switch to the new product and services bundles, thereby reducing total cost for all partners. Over the long run, product and service bundling might lead to usage-based pricing models in which customers will stop paying for printers and cartridges, but receive monthly bills for the number of pages printed or hours of light on desk and wall. Then, customers will no longer pay for means of production, only for services consumed.

4. Discussion: Challenges and Risks

This article has so far been arguing along the following lines: Despite heavy investment in integrated information systems, many business problems still remain due to a lack of integration between the real and virtual worlds. Low data granularity presently limits enterprise computing. To solve the problems, data granularity needs to be increased and the digital management control loop needs to be closed. Pervasive Computing including automatic identification is the appropriate technological enabler. Once closed digital management control loops are in place, generating high data granularity, incremental process changes such as automatic quality checks will increase overall process efficiency. Value logging and embedded services are examples of more radical changes that will not only affect processes, but also business models.

However, although this development has been based on theoretical foundations, such as the theory of integration and transaction costs, and has been derived from numerous cases, many counterarguments if not worries still exist. In the following paragraphs, some will be briefly discussed.

Increase data granularity. The data granularity approach stresses that more data are needed to solve business problems. It thus conflicts with many familiar concepts. Critics might suggest that we already have too much data and we get lost in junk data. From biology, such as from the way a fly controls its flight, we know that nature uses massive data filtering, eventually using very few signals for handling complex situations.Onthe other hand, complexity theory stresses that only variety can handle variety. Every new level of detail and individuality requires new data.

Replace statistics with real data. From selling airplane tickets to tracking fraud in the mail order business, we currently solve many problems surprisingly exactly, using statistics at very low cost. Therefore, why should businesses switch to a more expensive method? Ultimately, the individual business may need to decide whether to use Pervasive Computing technologies or other methods to solve a problem. In many applications currently conducted by businesses, such as large-scale item tagging in retailing, we find that classical methods will still prevail for a long time.

Technocratic approach. Companies try to solve problems generated by current generation technology by developing next-generation technology. For instance, in principle, most of the information needed to solve a supermarket's out-of-stock problem could be handled by means of state-of-the-art systems and concepts such as scanner checkouts, efficient consumer response, electronic data interchange, and so on. New technologies not only offer new functionality, which could add up to more than the sum of the technologies in place; for example, whether the new investment really closes the digital control loop, also leveraging some older technology investments. In some cases, new technology might also provide new impetus for solving familiar problems with older technology.

Integration of both worlds. Who really wants the seamless integration of the real with the virtual world? Both consumers and employees are unlikely to opt for the integration the two worlds at an abstract level, because they will not see any benefit to them, only threads. However, we have learned from history that consumers and employees almost always opt for convenience at the right price. Thus, whenever a technology makes life a little easier, people are likely to adopt it. Currently, Pervasive Computing technology will, most of all, make life easier in the working environment. To have pervasive technology accepted in the home environment, an application, which really promotes convenience, has to be available in the market.

Technical risks. Information systems, communication infrastructure, and engineers are used to dealing with massive amounts of data. However, our systems and engineers are not prepared to manage the "last mile" to the object which, in terms of passive RFID systems, is about 1–2 meters. Most business scenarios deal with the last mile as if it would function as simply and cost efficiently as "plug and play" technology such as the Ethernet or USP. However, the issues of mismatching protocols, frequency spectrums and power levels of metal and liquids and other disturbance variables, still prevail and have the potential to slow down the currently rather dynamic movements in the area of automatic identification.

Dependency on technology.

Businesses will depend on Pervasive Computing systems as much as they depend on other human-out-of-the-loop systems that they operate. As in the other systems, Pervasive Computing systems have to feature selfchecking routines, redundancy concepts, and most importantly of all, interfaces to employees, which supports systems transparency and exception handling.

Change of jobs.

Pervasive technologies automate tasks currently done by lowskill workers. For instance, in future warehouses inbound and outbound logistics departments are very likely to use RFID technologies to perform many of their quality checks, thereby putting workers out of jobs. Of course, new technology requires new jobs, but a retraining of those people losing their employment is often difficult—the job requirements differ too much. However, the customer-driven and thus highly competitive market will eventually force many companies to adopt new and more cost-efficient technologies, thereby initiating job changes.

Embedded services lock in customers. Pervasive Computing can be used to establish a strong link between products and product-related services. Product companies could, therefore, use pervasive technologies to force customers to buy their services subject to unfair conditions. In addition, the measures mentioned in the corresponding earlier section demonstrate that it is important to avoid a monopolistic situation, that is, to facilitate a service market in which sophisticated customers can manipulate market forces. Companies with unfair models will then eventually lose customer base and business.

Change always costs money. Bearing in mind all the exiting scenarios published in the daily press internationally—from the milk-ordering fridge to the dress-ordering doll—we must not forget that every technology change costs money, that every product redesign, chip, sensor, and communication channel has to be paid for. Given the issue of money, many of those scenarios will remain fiction or laboratory demonstrations. Only scenarios with a compelling business justification will prevail in the real world. However, this also holds true for the military and other sectors.

Emotions. Pervasive Computing enhances the communication capabilities of objects. It thus can evoke a new dimension of emotions in people confronted with these. The product company might use its product's communication capabilities for special advertising, striving toward a stronger emotional bonding between consumer and company. Alternatively, it might sell the capabilities to other organizations as in the manner of space salesmen. However, up to the present, it seems largely unclear how companies will leverage this powerful marketing tool, which adds another dimension to current industrial-design-based product communication.

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