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Assessing the Human, Social, and Environmental Risks of Pervasive Computing

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ABSTRACT

The vision of Pervasive Computing is built on the assumption that computers will become part of everyday objects, augmenting them with information services and enhanced functionality. This article reports on the approach we have used to assess potential side effects of this development on human health and the environment, and the major risks we identified. Social risks such as the risk of conflicts between users and non-users of the technology were also included because of their potential indirect adverse health effects. Assessing a technological vision before it has materialized makes it necessary to deal with two types of uncertainty: first, the uncertainty of how fast and to what extent the technology will be taken up and how it will be used; second, the uncertainty of causal models connecting technology-related causes with potential health or environmental effects. Due to these uncertainties, quantitative methods to evaluate expected risks are inadequate. Instead, we developed a "risk filter" that makes it possible to rank risks according to a set of qualitative criteria based on the Precautionary Principle. As the overall result, it turned out that Pervasive Computing bears potential risks to health, society, and/or the environment in the following fields: Non-ionizing radiation, stress imposed on the user, restriction of consumers' and patients' freedom of choice, threats to ecological sustainability, and dissipation of responsibility in computer-controlled environments.

Key Words: Pervasive Computing, ubiquitous computing, ambient intelligence, qualitative risk assessment, risk filter.

1. INTRODUCTION

Due to the ongoing trends of miniaturization and integration in Information and Communication Technologies (ICT), programmable microprocessors will invade numerous everyday objects, enabling them to expand their functionality with information services. The ICT components will be unobtrusive, almost invisible and

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connected via wireless networks. In contrast to today's ICT devices, they will also be equipped with sensors making them context sensitive (PERVASIVE 2004).

This technological vision is called *Pervasive Computing*, *Ubiquitous Computing*, or *Ambient Intelligence*. In 2002, the Swiss Center for Technology Assessment (TA-SWISS) contracted with the authors to conduct a technology assessment study on the potential impacts of Pervasive Computing on human health and the environment. We show in this article how we solved the methodological problems of assessing a technological vision before it has materialized, and what main results we obtained. The full study has been published in German (Hilty *et al.* 2003). An English translation will be available by the end of 2004.

The reason for assessing technological risks at an early stage of development is the experience that full evidence for the existence of a risk is sometimes only available after severe damage has occurred. For example, the fact that chlorinated fluorocarbons (CFCs) harm the atmospheric ozone layer was not proven until after the ozone hole had been discovered (EEA 2001). According to the Precautionary Principle, we use an approach to risk assessment that is applicable before full empirical evidence is available. The study for TA-SWISS was one of the first attempts to apply the Precautionary Principle to a mass consumer technology (see also Som *et al.* 2004).

Technology assessment based on the Precautionary Principle must be able to deal with two types of uncertainty. First, how the technology and the market will develop are open questions. We cannot predict with sufficient accuracy how fast and to which extent the technology will be taken up and how it will be used. Many predictions in the past have turned out to be wrong (*e.g.*, nobody adequately predicted the success of SMS). Because of this reason, it is necessary to create scenarios describing *possible* paths of development, and base one's conclusions on the scenarios. Second, the causal models connecting technology-related causes and potential negative effects on health or the environment are uncertain. For instance, there is still uncertainty as to whether exposure to non-ionizing radiation has non-thermal biological effects that can harm human health.

The first type of uncertainty can be dealt with by making conditional statements about the risks identified: If real events approximate scenario x, there will be a y risk. Conditional statements lead directly to recommendations for measures to minimize the risk, because actions may influence which scenario will become real, and they will usually differ in the risks they bring about. The second type of uncertainty—uncertainty of causal models—leads to the notion of *potential risk*, which is common in the context of the Precautionary Principle. At a first glance, "potential risk" seems to be a pleonasm, because a "risk" means "potential damage" (a damage that will not occur with certainty, but with a probability p where $0 < p < 1$). It follows that the term "potential risk" can be read as "potential potential damage," which looks like a mistake. However, this term has a precise meaning if one allocates the first "potential" to the existence of the causal mechanism (there is a possibility that it exists), and the second one to its stochastic nature (if there is a causal mechanism, it is not deterministic).

It follows that technology assessment based on the Precautionary Principle is searching for *potential risks* (in the sense just explained) related to the technology under study, occurring under conditions described in scenarios. The results of such a study have the form of conditional statements from which measures can be derived to minimize potential risks. The term *uncertain risk* is used synonymously with *potential risk* in the context of the Precautionary Principle.

The first approach to dealing with uncertainty is to quantify it (estimate the error) and use error propagation. Various methods have been developed to quantify uncertainty in human and ecological risk assessment (Crump 2003; Finkel 2002; Hoffmann *et al.* 1999; Peterman and Anderson 1999). However, if nothing is known about the distribution of the error (which is true for both the scenario-related error and for the model-related error), this type of approach does not seem applicable. The routine of using quantitative risk assessment in such situations would be misleading (Hardman and Ayton 1997).

We must conclude that *quantitative* risk assessment is not a suitable approach for the type of study discussed here. Instead, it seems necessary to use *qualitative* criteria to evaluate potential risks. These criteria are essential to separate the wheat from the chaff, that is, to select the most relevant potential risks from an initial list of potential risks. The initial list is potentially infinite, but practically limited by the amount of time allocated for the first screening for potential risks. The criteria filter out the potential risks according to their severity. Therefore, we call such a set of criteria a *risk filter*. Risk filters have also been used in environmental chemistry (Müller-Herold 2002). The definition of such criteria is based on a system of values, that is, it cannot be done without prejudice. The following section describes the methodology of qualitative risk assessment—including the criteria and the value system—we have used in the case of Pervasive Computing.

2. METHODOLOGY

The methodology we used in the technology assessment study of Pervasive Computing (Hilty *et al.* 2003) consists of three steps: (1) developing scenarios, (2) screening for potential risks, and (3) applying the risk filter. The risk filter will be explained in more detail than for the first two steps, because this approach is based on a system of values that have to be stated explicitly. Our method is based on qualitative criteria established for characterizing risks (Klinke and Renn 2002; Mehl 2001; Wiedemann and Brüggemann 2001) and on the concept of a risk filter (Müller-Herold 2002).

2.1. Scenario Development

Before we started to develop scenarios, we selected four application areas of Pervasive Computing in order to define a focus. We selected the areas of traffic, housing, work, and health. Health as an *application area* of Pervasive Computing should not be confused with health as a *subject of protection* from the risks of this technology. There may be potential health risks of Pervasive Computing in all application areas, including the health sector.

Focusing on the four application areas, we developed three scenarios representing the development of the technology and the market, each set for a 10-year time horizon:

- a "cautious" scenario based on the assumption that consumers would adopt the technology very cautiously, that is, there would be no "market pull" but only a "technology push" to foster Pervasive Computing;
- a "high-tech" scenario based on the assumption that everything that is technologically and economically feasible would be accepted and demanded by consumers;
- an "average" scenario reflecting a plausible compromise between the other two.

The three scenarios for these application fields are described in detail in the original study (Hilty *et al.* 2003). We then used the scenarios to do a screening for potential risks.

2.2. Screening for Potential Risks

In order to create an initial list of the potential risks of Pervasive Computing, we organized two expert workshops. For the first workshop we invited experts from academic disciplines involved in the development or in the potential impacts of the technology under study (electronic engineering, computer science, medicine, environmental science, social sciences, and ethics). The participants of the second workshop were selected according to their affiliation to stakeholder groups (consumer organizations, governmental agencies, computer and telecommunication industry, service organizations, representatives of corporate research and development, and politically committed scientists).

The outcome of this screening was a list of 23 potential risks (Tables 1–4). Among other things, the expert groups suggested that we include indirect health effects as well (in addition to direct health and environmental effects), which are addressed in Tables 2 (health-related effects) and 3 (social effects). In some cases, the experts found that the same cause can bring about an opportunity that is as remarkable as the risk. For this reason, we added a column for opportunities to each table. This

Table 1. Potential direct health effects of Pervasive Computing.

Code	Application area	Cause	Opportunity	Risk	State of knowledge
H-1	All	NIR exposure caused by Pervasive Computing	—	Health hazard caused by NIR	Highly uncertain
H-2	All	Physical contact with Pervasive Computing components	—	Health hazard caused by physical contact with microelectronics	Partly uncertain
H-3	Health	Use of active implants	Better therapy options	Health hazard caused by active implants	Risks partly uncertain

Table 2. Potential health-related effects of Pervasive Computing.

Code	Application area	Cause	Opportunity	Risk	Influence of the scenarios
R-1	All	Changed ICT environment due to Pervasive Computing	Reduced NIR exposition	Increased NIR exposition	Reduction occurs only in average scenario under optimistic assumptions
R-2	All	New forms of human–machine interaction	Less stress due to better ergonomics	More stress due to poor ergonomics	Opportunity always exists, it is inevitable in the high-tech scenario
R-3	All	Dependency on ubiquitous ICT	—	Stress due to subjectively unpredictable behavior of technical systems	Risk grows with the degree of ubiquity and networking
R-4	All	Ubiquity of ICT	—	Stress due to overstimulation and distraction	Considerable risk in the average scenario, unclear in the high-tech scenario
R-5	Health	Extensive health monitoring	Healthier lifestyle	e-doping	Both opportunities and risks in the average and the high-tech scenario
R-6	Health	Better technologies for medical diagnosis, treatment, and care	More autonomy for patients	Psychological side effects of high-tech health care	Risks predominate in the high-tech scenario
R-7	Health	Changed cost structure in the public health sector	Contribution to stabilization of costs in the public health system	Rapid increase in health care costs	Both opportunities and risks are low in the cautious scenario; outcome depends on policies in the other scenarios
R-8	Traffic	Driver support systems	Greater safety in traffic	Increase in number of traffic accidents	Risks predominate in the high-tech scenario

Table 3. Potential social effects of Pervasive Computing.

Code	Application area	Cause	Opportunity	Risk	Influence of the scenarios
S-1	All	Pervasion of everyday life by ICT	Reduction of the digital divide	Restriction of consumers' freedom of choice	Opportunity may predominate in the cautious scenario
S-2	All	Ubiquitous information access	More efficient access to information and knowledge	Economy of attention begins to dominate culture	Risks predominate in the high-tech scenario
S-3	All	Ubiquitous information access	Emergence of virtual communities	Loss of social contacts, isolation	Unclear, depending on other factors
S-4	All	Observance and identification with ICT	Better protection from criminal actions	Undermining of privacy regulations	Opportunity may predominate in the cautious scenario
S-5	All	Ubiquity, embedding, networking of ICT	—	New forms of computer crime	Increase with the degree of diffusion and networking
S-6	All	Extension not controllable complexity	—	Undermining of the causation principle	Increase with the degree of diffusion and networking

shows the high uncertainty with which our assessment has to deal. The content of the tables will be explained in Section 3.

From the methodological point of view it is important to note that the effects are "pre-filtered" by implicit or explicit relevance decisions of the group of experts. However, there is no way to go beyond implicit relevance assignment and identify *a priori* issues to be discussed in a given context. Thus our methodology—like any other—cannot guard against ignorance about potential risks that might turn out to be the most important ones from a later perspective.

After the screening based on the two workshops, we constructed the risk filter in order to separate the wheat from the chaff and—as a beneficial side-effect of the filtering—to recognize which risks have similar characteristics and can be clustered for complexity reduction.

2.3. The Risk Filter

Before we explain the risk filter that we created for the project reported here, let us briefly introduce the filter for environmental chemistry defined by Müller-Herold (2002) in order to illustrate the basic idea first. Müller-Herold's risk filter was created to aid in the assessment of chemicals whose impacts were only rudimentarily known, that is, knowledge about the risks induced by releasing them to the environment

Table 4. Potential environmental effects of Pervasive Computing.

Code	Application area	Cause	Opportunity	Risk	Influence of the scenarios
E-1	All	Miniaturization of ICT devices	Less ICT-induced material use	Increased use of precious and toxic materials	Depending on the framework conditions assumed
E-2	All	Mobile devices dominate ICT	Less ICT-induced power consumption	Increased power consumption due to ICT	Depending on the framework conditions assumed
E-3	All	Disposal of large amounts of small electronic components	—	Disposal problems caused by electronics	Increasing with the diffusion rate
E-4	All	Electronic components embedded into everyday objects	—	Short product service lives due to "virtual wear-out"	Risks in the average and high-tech scenarios
E-5	Housing	Smart home	Less residential energy consumption	Increased residential energy consumption	Both opportunities and risks in the high-tech scenario
E-6	Work	Increased independence of activities from the location	Decrease in energy-intensive mobility	Increase in energy-intensive mobility	Depending on the framework conditions assumed

was highly uncertain. However, even if the characteristics of the risks were hardly known, there were basic criteria to distinguish between "better" and "worse" risks. In comparing new chemicals, we would, for example, consider a chemical that tends to be persistent and bioaccumulating as being riskier than a chemical that does not persist or bio-accumulate. The filter is a system of criteria such as persistency or bioaccumulation.

Our task was to find criteria that were applicable to the potential risks considered in the context of Pervasive Computing (or some similar mass consumer technology) and fulfill their purpose in being selective with regard to the initial list of potential risks. We referred to the extensive work on qualitative risk characterization by Klinke and Renn (2002), who used the following criteria to characterize risks: uncertainty, ubiquity, persistency, reversibility, the delay effect, and the potential to mobilize society. We also considered criteria such as voluntariness, controllability, trust, fairness, and potential for catastrophes discussed in the literature of risk perception and risk acceptance (Mehl 2001; Wiedemann and Brüggemann 2001). As our filter was supposed to be clear and simple in order to be useful in a political discourse, we selected only four criteria:

- Socioeconomic irreversibility: Will it be practically impossible to restore the status before the addressed effect of the technology has occurred? (Example: car accidents are a socioeconomically irreversible risk of automobile technology.)
- Delay effect: Is the time span between the technological cause and the potential negative effect long compared to the diffusion speed of the technology?
- Potential for conflicts, with the subcriteria:
  - Voluntariness: Is exposure to the risk voluntary? If not, there is a high conflict potential.
  - Fairness: Do the same people benefit from the opportunities the technology as those who suffer from the risks? If not, there is high conflict potential.
- Burden on posterity: Does the technology and its potential effects compromise the possibilities of future generations to meet their needs?

In selecting these criteria, we tried to build on the most basic (and therefore universal) values as possible. A basic value system is embodied by the principles of traditional ethics, such as the autonomy principle (from which the voluntariness criterion is derived) and the fairness principle. The latter leads to the fairness criterion and, if temporally extended, to the "burden on posterity" criterion. This extension of the traditional fairness principle is part of the concept of sustainable development (WCED 1987) and widely accepted today.

The first two criteria can be defended without making reference to ethical values, but to the principle of rational choice. If a choice is to be made under high (and even unquantifiable) uncertainty, it is rational to choose the alternative that keeps the most freedom for future decisions open. This is because it is possible—and in most cases very likely—that the uncertainty will decrease as time goes on, and better decisions can be made later, assuming that the alternatives are still open. A choice with potentially irreversible consequences is most unfavorable from this point of view.

Irreversibility in a strict sense can only be based on natural science. However, in order to assess the impacts of a novel technology on society, it is very plausible to account for "weaker" concepts of irreversibility based on cultural facts such as "socioeconomic irreversiblity": "Nevertheless, in contrast to biological evolution, cultural and technical evolution is partially reversible. . . . In this context the power of cultural processes should not be underestimated" (Rammel 2003, p. 402).

A similar argument can be used to defend the "delay effect" criterion. Under high uncertainty, it is more rational to choose an alternative that contributes to a reduction of the uncertainty in shorter time. A long delay between cause and effect extends the time span of uncertainty and potentially leads to a situation with much higher damage because the cause has been given more time to spread before the effects were observed and countermeasures could be taken.

However, in order to use the criteria rationally, they must be applied symmetrically to all alternatives given. For example, if measures to inhibit some applications of a technology are discussed, both the risks of having or not having these applications must be evaluated using all criteria in the same way.

3. QUALITATIVE ASSESSMENT OF POTENTIAL RISKS OF PERVASIVE COMPUTING

In this section we describe the potential risks of Pervasive Computing as they were identified in the two expert workshops of the project and then show how we used the risk filter defined in the previous section to reduce the set of potential risks to the most relevant ones, and to reduce complexity by clustering risks with similar characteristics.

3.1. Results of an Initial Screening for Potential Risks of Pervasive Computing

The first screening for potential risks of Pervasive Computing done by the participants of two expert workshops yielded the results shown in Tables 1–4.

The potential direct effects on human health are shown in Table 1 and will be explained in Section 3.1.1. One outcome of the two workshops was that it is necessary to cover indirect along with direct health effects, because a technology such as Pervasive Computing may affect human health much more on indirect paths than directly. For this reason, we added the categories of potential health-related effects (Table 2, Section 3.1.2) and potential social effects (Table 3, Section 3.1.3). Table 4 (Section 3.1.4) shows potential environmental effects.

During the project, codes of the form “H-1” were assigned to the risks in order to enable concise reference. We will use these codes in the following text as well. For reference, please refer to Tables 1–4, which show the code in the first column. The second column of each table shows the application area affected by the risk.

3.1.1. Direct health effects of pervasive computing

Table 1 summarizes the potential direct effects of Pervasive Computing for human health. The column “state of knowledge” indicates the degree of uncertainty.

H-1. Health Hazard Caused by Non-Ionizing Radiation. Non-ionizing radiation (NIR) is emitted for wireless data transfer, which is one of the basic technologies of Pervasive Computing. NIR includes radio frequencies (RF) up to 30 GHz, which are used for many purposes. As nowadays wireless communication is widely used (cellular phones, cordless phones, wireless local area networks [WLAN]), the public is concerned about the potential long-term health effects caused by exposure to NIR from base transmitter stations and terminal devices.

It is undisputed that health damage can result from thermal effects of high NIR-exposure. An NIR intensity above 100 W/kg affects body tissue. Thermal effects are prevented by limit values for the specific absorption rate of 2 W/kg for cellular phones.

The present discussion of the potential health risks of NIR refers to non-thermal effects. Many laboratory experiments have provided some evidence for such effects, including the study by Huber *et al.* (2000), which showed post-exposure effects on the human electroencephalogram (EEG) during sleep. The effects only occurred when subjects were exposed to a modulated signal with the modulation scheme of mobile phones; the non-modulated carrier signal did not evoke any measurable effect.

It is still unknown:

- Which causal mechanism(s) explain(s) the non-thermal biological effects of NIR like the one observed by Huber *et al.* (2000).
- If such effects cause health damage.
- If serious non-thermal biological long-term effects of NIR exposure exist.

Besides the biological effects, attention should be given to the psychosomatic effects of NIR exposure. The mere fear of NIR can also lead to real health symptoms.

Furthermore, it is an open question as to whether the sensitivity for electromagnetic fields that some people claim to have is based on a biological mechanism.

H-2. Health Hazards Caused by Physical Contact with Microelectronics. With the growing numbers of wearable devices, a more intensive dermal contact with the surface of electronics products (usually polymers with additives) is very likely. Grit and effluvium can be resorbed or inhaled in the body during longer periods. Due to the wide range of substances used for microelectronics, the risk of allergic reactions or chronic poisoning increases. The level of risk depends on the substances contained and the kind of encapsulation (or other design measures) used to prevent abrasion or effluvium.

In the future, new types of microelectronics will emerge that may release new potentially harmful substances, for example, nano-particles or nano-tubes (intended to be used in flat screens of all sizes) with new surface properties.

H-3. Better Therapy Options/Health Hazards Caused by Active Implants. Active microelectronic implants inside the human body provide far-reaching therapeutic opportunities. They can be used as components of computer-controlled prostheses such as brain pacemakers or for artificial sensory organs (sensory prostheses).

If the side effects of active implants are not investigated systematically, the risks could outweigh the benefits. Possible side effects can be:

- Health reactions to substances resolved from the implant surface due to the influence of the biological environment,
- Influence on the functionality and behavior of cells that are in direct contact with the implant surface; this may occur by protein adsorption and denaturation on the implant surface,
- Mechanical stress within the body tissues surrounding the implant,
- Disturbance of cell-to-cell interaction caused by electric or optical activity,
- Emission of electromagnetic field by implants; even low transmitting power can cause high local NIR exposure within body tissue.

Those risks can be influenced by design engineering of the implant wrapping and clinical testing. In addition there is a need for further research.

3.2. Health-Related Effects of Pervasive Computing

In addition to the direct health effects of Pervasive Computing, we considered effects on factors that influence health, for example, stress or fears caused by this technology. This yielded the list shown in Table 2.

The effects on the health-related factors depend more on the assumptions made about the penetration rate and the degree of connectivity supposed to be reached by Pervasive Computing than on other types of uncertainty, that is, they highly depend on the scenario chosen. The scenario may even decide whether an effect of the technology will manifest itself as an opportunity or a risk. For this reason, the last column of Table 2 indicates how the effects relate to the scenarios (as introduced in Section 2.1).

R-1. Reduced NIR Exposure/Increased NIR Exposure. Depending on technical details and the diffusion rate of the technology, Pervasive Computing can cause either a reduction or an increase in average NIR-exposure for humans. A reduction is possible under the following conditions:

1. The use of wireless local area networks (W-LANs) and similar technologies largely replaces the use of mobile phone networks wherever possible. This would require the use of RF-devices that are switchable from wide-range cellular network (GSM or UMTS) to short-range W-LAN or Bluetooth in local contexts. Short-range connections cause less NIR emissions compared with established cellular networks (Wüertenberger and Behrendt 2004).
2. The near-body use of wireless devices does not escalate.

We estimate the probability that both conditions will be met as very low. Unless policies are designed that set incentives for short-range communication *and* against body area networks, it should be assumed that Pervasive Computing will cause an increase in average NIR exposure.

R-2. Less Stress Due to Better Ergonomics/More Stress Due to Poor Ergonomics. As today's ICT shows, it is a difficult task to design user-adequate human–computer interfaces. Pervasive Computing will only be possible if much progress is made in ICT ergonomics. The vision of Pervasive Computing, first announced by Mark Weiser, included the requirement to shape the technology in such a way that it will be invisible and "does not intrude on your consciousness" (Weiser 1994, p. 7). Given the high-tech scenario, this is mandatory, because otherwise ICT-induced stress will increase according to the number of devices that are used per person. ICT ergonomics may turn out to be the greatest challenge for the developers of Pervasive Computing.

R-3. Stress Due to Subjectively Unpredictable Behavior of Technical Systems. Due to the complexity of ICT systems, which will increase when more distributed hardware-software systems are used, their behavior does not always comply with reasonable expectations of the user. The systems' behavior is therefore perceived as unpredictable, although it is predictable from a theoretical point of view.

Along with the increasing dependence on complex ICT systems, the potential damage caused by a mismatch between the users' mental models of the systems and the systems' behavior increases. Accordingly the stress imposed on the users will increase as the possible consequences of computer failure will be more severe than today.

R-4. Stress Due to Overstimulation and Distraction. There is a general trend to overstimulation and distraction by ICT devices, such as ringing mobile phones. If this trend continues, it may lead to increasing stress in many situations of daily life. ICT-related disturbances are likely to increase in the future due to the increasing density of Pervasive Computing devices.

R-5. Healthier Lifestyle/"e-Doping."

Monitoring physiological parameters by devices based on Pervasive Computing brings benefits for health-conscious people or for patients in a rehabilitation phase. Physiological feedback by health monitoring devices could guide people to a healthier lifestyle.

However, the same technology can be used for exceeding the capacity of the human body for a short time, taking a calculable risk. Used for this type of monitoring, Pervasive Computing could give rise to a new kind of doping that could be called "e-doping."

R-6. More Autonomy for Patients/Psychological Side Effects of High-Tech Health Care. Pervasive Computing will reduce the dependency of patients on auxiliary and care personnel, shorten hospital stays, and improve patients' information level. This all offers the opportunity that patients' autonomy will be maintained throughout the course of treatment.

However, using technology more usually means needing fewer personnel. One more step in the direction of "machine medicine" might set off psychic side effects such as the feeling of being under surveillance and helpless, or fear for technical breakdowns. This is to be expected in particular whenever the surveillance is involuntary or partially involuntary such as being under pressure from one's health insurance provider.

R-7. Contribution to Stabilization of Costs in the Public Health System/Rapid Increase in Health Care Costs. Cost savings, early detection of diseases, and other effects of Pervasive Computing on health matters could help to lower costs. However, at the same time new, and possibly costly therapies might exert new, upward cost pressure in cases where many people are affected by the changes.

R-8. Greater Safety in Traffic/Increase in the Number of Traffic Accidents. Additional surveillance and control systems for vehicles and drivers may increase traffic safety. However, unless the technical complexity of the systems used and their autonomy are limited severely, the risks may prevail. They lie on the one hand in the area of technical breakdown (software errors with disastrous consequences) and on the other hand in a possibly higher driver willingness to take risks as a result of the increased safety perception. This was the lesson from experience with anti-skid braking systems (ABS) (Schibalski 2002).

In addition, any systems that distract drivers from their main activity are high in risk.

3.2.1. Social effects of pervasive computing

Social effects of Pervasive Computing have to be seen as health relevant in the broadest sense. Compared to the direct health effects or environmental risks the socioeconomic effects are coupled with a higher degree of uncertainty.

S-1. Reduction of the Digital Divide/Restriction of Consumers' Freedom of Choice. Separation of society into groups of those persons who have access to ICT and those who do not is known as the "digital divide." Access to the Internet is the central criterion today.

The opportunities outlined earlier to carry on new forms of human–computer interaction will make it possible to lower the threshold limiting the use of ICT. For example, using a keyboard will be necessary in ever-fewer cases. It will also be easier to develop applications that permit handicapped and sick persons to have access for the first time, or easier access if already online.

At the same time a risk exists that consumer freedom will be limited for the following reasons:

- Persons who do not want to use ICT for certain activities (such as banking) might be put at such a disadvantage by changes in the structures of the offering that they would be practically forced to use ICT.
- ICT relies on technical standards to a high degree, and this applies especially when a high percentage of people are connected. If proprietary de-facto standards continue to play a significant role, a loss in competition may occur.

In the first case the consumer can no longer decide freely *for what* he is using ICT or not. In the second case the consumer no longer has the choice *which* ICT products or ICT services he uses, because the ICT market is taking on a "winner takes it all" structure.

S-2. More Efficient Access to Information and Knowledge/Economy of Attention Begins to Dominate Culture. Access to information and knowledge will work more efficiently under Pervasive Computing. Access will be possible everywhere and anytime (pervasiveness), and still be dependent on the environment (context sensitivity). The user will be flooded with information even more than is the case on the Internet today. The conscious attention of the user will become a scarce resource. Advertisers will fight hard and harder to commercially exploit this resource.

S-3. Emergence of Virtual Communities/Loss of Social Contacts, Isolation. Virtual communities are groups of people with common interests who share experiences despite geographical distances and can speak as a community. The Internet has already produced a vast number of such communities, for instance, to share experiences about rare diseases, for political or ethnic minorities, and so on. Virtual space makes it possible for communities to form, which would not exist in real space because they would be too dispersed. Pervasive Computing could accentuate this trend because the access threshold would be lower than is the case with Internet access on a PC.

When one escapes frequently to a virtual world, the risk arises of losing social contacts in the real world. Being able to access the virtual world anywhere and everywhere will probably increase the trend to addiction, which can already be seen today in the case of the Internet (Schauer 2002).

S-4. Better Protection from Criminal Actions/Undermining of Privacy Regulations. The opportunity exists to protect buildings and facilities better from unauthorized access using complete and low-cost surveillance and new ways to identify persons. Protecting objects from theft will be made much easier with "smart labels" and other identification systems. Monitoring other persons' data traffic (for instance, their Internet access statistics) and wiretapping telephone conversations can contribute to crime prevention. The same technology, however, can also be used to intrude into the private sphere of other persons and to record images and sounds without the knowledge of those affected, to register their locations, to monitor their data traffic, and to store and pass on the data obtained in these ways. Pervasive Computing will make it difficult, if not impossible, to implement privacy regulations.

S-5. New Forms of Computer Crime. Just as the Internet brought with it new forms of criminality, so too will Pervasive Computing also open up new ways to abuse criminally the refined networking, embedding, and pervasiveness of ICT. One difference this time will be that embedded systems not only process information, but also can control physical processes.

Unauthorized influencing of systems of Pervasive Computing can take place by:

- Reprogramming components.
- Directly influencing components by means of radio waves.
- Influencing through networks
  - by unauthorized access (network hacking),
  - by denial-of-service attacks,
  - by spreading computer viruses,
  - by interrupting radio wave or cable connections.

Considering that Pervasive Computing is expected to bring with it both a higher degree of networking and progress in the usability of systems, we find it hard to imagine that it will be possible to keep data and network security at an acceptable level.

S-6. Undermining of the Causation Principle. Whenever a Pervasive Computing system causes damage, the complexity of the systems is likely to make it very difficult to find the cause. System behavior is determined by the interplay of numerous software products, hardware products, user interaction, network protocols, and so on. Here the causation principle comes up against limits because of a complexity created by humans that they no longer master.

3.3. Environmental Effects of Pervasive Computing

E-1. Less ICT-Induced Material Use/Increased Use of Precious and Toxic Materials. Due to the miniaturization of Pervasive Computing devices ICT products' specific demand for raw materials (kg per device) will decrease. Only in the cautious scenario does this result in a reduction of the total demand for raw materials in the

ICT-sector. A compensation or even over-compensation is more likely, as the number of components produced increases sharply. This can be expected for the following reasons:

- the vision of Pervasive Computing predicts a large number of components used in parallel to one another;
- price reduction will shorten the average use time of Pervasive Computing components (trend toward disposable products).

Thus, there is a risk of increasing consumption of raw materials by the ICT sector.

E-2. Less ICT-Induced Power Consumption/Increased Power Consumption Due to ICT. There exists a great opportunity for power savings during the use phase of mobile Pervasive Computing devices, because the acceptable weight of mobile devices limits battery size. Additionally a change or recharging of large numbers of batteries is unacceptable for users. A supply based on decentralized energy sources such as photovoltaics, fuel cells, or the use of body energy will be necessary.

However, the risk of additional total power consumption may predominate if incentives are not provided for energy-saving design of the stationary infrastructures needed to handle the contents and services for Pervasive Computing applications (Türk *et al.* 2002).

E-3. Disposal Problems Caused by Electronics. The end-of-life treatment of Pervasive Computing components will have to deal with large numbers of small microelectronic components embedded in other products. In many cases they will contain small rechargeable batteries. In mass application a release of toxic substances into the environment could become a relevant threat unless the e-waste is disposed of in a responsible manner.

The invisibility of Pervasive Computing in many products makes it more difficult for consumers to differentiate between electronics and non-electronics. That will complicate any waste separation by consumers. Cross-contamination between electronics waste streams and other waste streams is a serious environmental risk of Pervasive Computing (for quantitative estimates see Koehler and Erdmann 2004).

E-4. Short Product Service Lives Due to "Virtual Wear-Out." The service life of products is an essential parameter for the lifecycle-wide material and energy use per service unit. Halving service life means doubling the resources used for production as well as the amount of waste (per service unit). ICT products often are scrapped after a service life of only 10–50% of their technically possible lifetime because of short innovation cycles and software incompatibility problems.

The risk exists that this development will spread to objects in which ICT components are embedded. For example, a networked refrigerator could be replaced because the old model was not compatible with a new network protocol. We have introduced the term "virtual wear-out" for this conceivable effect. Given the wide variety of embedded systems to be expected as a result of the Pervasive Computing vision, that would be a setback for the efforts to attain sustainability.

E-5. Less Residential Energy Consumption/Increased Residential Energy Consumption. Basically the vision of the "smart home" offers the opportunity of optimally controlling the processes that are energetically relevant in buildings. Unnecessary losses can be avoided better than they can today (see also Hilty *et al.* 2004).

Unless incentives are provided to conserve energy, the risk exists that the additional use of basis stations and servers that are on all the time and devices with significant standby consumption will increase total energy consumption.

E-6. Decrease in Energy-Intensive Mobility/Increase in Energy-Intensive Mobility. Pervasive Computing offers good conditions for substituting virtual presence for physical presence. The opportunity exists that cooperation in teams independent of location will become a natural part of work culture, if the ergonomic weaknesses of today's tele-conferencing applications can be overcome.

However, this benefit is opposed by the risk of a rebound effect (the time saved would be used for more trips) and the additional problem that being independent of location can give rise to greater mobility, especially as regards involvement in activities and relations at locations quite remote from one another.

3.4. Application of the Risk Filter

In order to reduce complexity, we reduce the initial 23 risks described earlier to 17 risks by grouping similar risks:

- Risks related to non-ionizing radiation: H-1 (health hazard caused by non-ionizing radiation) and R-1 (exposure to non-ionizing radiation).
- Risks related to user stress: R-2 (poor ergonomics), R-3 (unpredictable behavior of technical systems), R-4 (overstimulation and distraction).
- Risks concerning the lifecycle of materials: E-1 (material consumption), E-3 (disposal problems), E-6 (virtual wear-out).
- Risks related to energy consumption: E-2 (ICT-induced power consumption), E-7 (residential energy consumption).

The remaining risk groups consist of only one risk each. The first column of Table 5 shows the risk groups. Please refer to Tables 1–4 for the meaning of the codes. The opportunities contained in Tables 1–4 are no longer considered here, because the subject of this article is (qualitative) risk assessment. However, it should be noted that the result of the risk assessment should be interpreted and evaluated in the context of the opportunities Pervasive Computing offers to society; that is, however, beyond the scope of this article. As far as environmental effects are concerned, a more comprehensive picture has been given by Arnfalk *et al.* and Hilty *et al.* (2004) in a study for the European Commission.

The table shows how we applied the five criteria of the risk filter to the 17 risk groups. This was done by the project team based on the discussions in the expert workshops. Risks that did not score high on at least two of the criteria were no longer considered. In a second step, we clustered the risks showing a similar profile with regard to the criteria into risk *clusters.* The five resulting clusters are described in Section 3.5. The cluster descriptions also give the reasons for grouping items

Table 5. The 17 potential risks of Pervasive Computing that were identified and the application of the risk filter criteria. A dash (—) means that the criterion is not met or is met only marginally.

Code	Risk	Socioeconomic irreversibility	Delay effect	Conflict potential		Burden on posterity
				Voluntariness	Fairness	
H-1 R-1	Health hazards caused by non-ionizing radiation	High	Partially high*	Partially high	Partially high	—
H-2	Health hazards caused by physical contact with microelectronics	—	Low	—	—	—
H-3	Health hazards caused by active implants	—	High	—	—	—
R-2 R-3 R-4	Stress caused by pervasive technology	High	—	High	High	—
R-5	e-doping	—	—	—	Medium	—
R-6	Psychological side effects of high-tech health care	—	—	Medium	—	—
R-7	Rapid increase in health care costs	High	Medium	Medium	—	—
R-8	Increase in number of traffic accidents	—	—	Medium	Medium	—
S-1	Restriction of consumers' freedom of choice	High	Medium	High	—	—
S-2	Economy of attention begins to dominate culture	Medium	—	—	—	Low
S-3	Loss of social contacts, isolation	Low	—	—	—	—
S-4	Undermining of privacy regulations	High	Medium	High	High	—
S-5	New forms of computer crime	High	Medium	High	High	—
S-6	Undermining of the causation principle	High	Medium	High	High	Medium
E-1 E-3 E-4	Increased use of precious and toxic materials and disposal problems	High	—	—	Partially high	Partially high
E-2 E-5	Energy consumption caused by ICT infrastructure	High	—	—	Partially high	Medium
E-6	Increase in energy-intensive mobility	Very high	Medium	—	Partially high	High

*Low with respect to psychosomatic effects and so-called electro-sensitivity.

according to the individual criteria, which led to keeping the risk and being included in the risk cluster.

3.5. Results

The following risk clusters are the result of applying our qualitative risk filter to the risks listed in Table 5. These clusters are condensed descriptions of the potential risks of Pervasive Computing as found in the TA-SWISS study. For a more detailed explanation, please refer to the original study (Hilty *et al.* 2003).

Cluster 1 (H-1, R-1) Non-Ionizing Radiation—a Highly Uncertain Risk with High Conflict Potential. Exposure to non-ionizing radiation (NIR) is expected to increase due to Pervasive Computing, as the density of application increases. The near-body use of RF sources, which is usually voluntary, will cause the greatest exposure among individuals. But like the current discussion on NIR in the case of cellular phones, the conflict potential will mainly result from the involuntary part of the overall exposure. Non-users of Pervasive Computing will see themselves exposed to impairments caused by others carrying or wearing numerous NIR transmitters. This situation is likely to cause conflicts similar to the conflict between smokers and non-smokers (voluntariness and fairness criteria).

As the number of NIR transmitters increases dramatically, while there is still great uncertainty about the biological effects of NIR, the conflict potential will increase accordingly. If it should turn out in 20 or 30 years' time that NIR from Pervasive Computing components has negative long-term health effects, it would be practically impossible to replace this technology by a safe alternative providing the same functionality (delay effect and irreversibility criteria).

Cluster 2 (R-2, R-3, R-4, S-4, S-5): Stress Imposed on the User. Pervasive Computing can generate stress for various reasons, such as poor usability, disturbance and distraction, the feeling of being under surveillance (privacy issues), possible misuse of the technology for criminal purposes as well as increased demands on individuals' productivity. Stress has a considerable impact on health.

If society becomes dependent on this technology, which has characteristics of a new infrastructure, it will be difficult to undo the development (irreversibility criterion).

It is crucial to specify whether the users themselves take the risks mentioned earlier voluntarily. If the vision of Pervasive Computing is taken literally, there will be no way to get away (voluntariness criterion). If there are non-users, it is unlikely that they can be prevented from impairment (fairness criterion).

Cluster 3 (S-1, R-7): Restriction of Consumers' and Patients' Freedom of Choice. The trend toward Pervasive Computing may drive some consumers and patients into a situation in which they are compelled to use such technology (if, for instance, alternatives are no longer available) or to co-finance it against their will (as for example with rising mandatory contributions to health insurance).

Those restrictions on individual freedom, once established, could be difficult to lift again (irreversibility criterion) and may cause social conflicts, as they affect the social balance (fairness criterion).

Cluster 4 (E-1, E-2, E-3, E-4, E-5, E-6): Setbacks for Ecological Sustainability. The total use of scarce raw materials for the production of electronics and the total energy consumption of the stationary infrastructure of Pervasive Computing—necessary to provide contents and services—may increase sharply. Furthermore, if no adequate solution is found for the end-of-life treatment of the electronic waste generated by millions of very small components, precious raw materials will be lost and pollutants emitted to the environment.

Pervasive Computing increases the amount of activities that can be done independent of location. In the case of traffic this effect could cause an increase instead of substituting telecommunication for trips and flights. It appears likely on the basis of the empirical data obtained thus far that this induction effect will outweigh the substitution effect (see also Koehler and Erdmann 2004, *in this issue*).

That is already creating a conflict potential due to the global lack of balance in opportunities caused by technology on the one hand and environmental stress on the other (resource extraction, electronic waste disposal; E-waste Guide 2004). The locations with the most environmentally stressful activities are mostly located in less developed countries with lower environmental and social standards ("pollution havens," fairness criterion).

The accelerated extraction of valuable resources and the spreading of both valuable and damaging substances worldwide will be a burden on future generations (burden to posterity criterion).

Cluster 5 (S-6): Undermining of the Causation Principle. The basic principle that the party responsible is liable for the damages (causation principle) is increasingly difficult to enforce in computer-controlled environments. As a rule, it is not possible to isolate the cause of damages due to the combined effects of several components from computer hardware, programs, and data in networks, as it is practically impossible to cope with the complexity of such distributed ICT systems, either mathematically or legally.

As society's dependence on systems of this kind will grow with Pervasive Computing, a net increase in the damage derived from unmastered technical complexity has to be expected. As a consequence, a growing part of day-to-day life will, virtually, be removed from liability.

The problem will probably not become conscious until more areas of our everyday life are pervaded and controlled by networked computers (delay effect criterion). Once this development has taken place, it will be difficult to undo (irreversibility criterion). It bears a high conflict potential (voluntariness and fairness criteria). If people get accustomed to acting irresponsibly, they may cause damage that hurts future generations (burden to posterity criterion).

CONCLUSION AND OUTLOOK

In order to assess the human, social, and environmental risks of Pervasive Computing, we developed and used a qualitative approach. The uncertainty of how the technology and the market will develop was dealt with by using a scenario technique, and the uncertainty of causal models was dealt with by using a qualitative risk filter. The risk filter consisted of criteria that can be used to characterize risks, even if very little is known about the effects of the future application of the technology.

We used the following criteria to evaluate potential risks: socioeconomic irreversibility, the delay effect, conflict potential and burden on posterity, and identified the following issues as being the most relevant from the perspective of the Precautionary Principle:

- Non-ionizing radiation: Average exposure is expected to increase. There is a conflict potential, as non-users of Pervasive Computing will see themselves exposed to impairments caused by others. It is imperative to do further research on the possible health risks.
- Stress imposed on the user: Pervasive Computing can generate stress for various reasons, such as poor usability, disturbance and distraction, the feeling of being under surveillance (privacy issues), possible misuse of the technology for criminal purposes, as well as increased demands on individuals' productivity. Stress has a considerable impact on health.
- Restriction of consumers' and patients' freedom of choice: The trend toward Pervasive Computing may drive some consumers and patients into a situation in which they are compelled to use such technology (if, for instance, alternatives are no longer available) or to co-finance it against their will (as, for example, with rising mandatory contributions to health insurance).
- Setbacks for ecological sustainability: Consumption of scarce raw materials for the production of electronics and the energy consumption of stationary ICT infrastructure may increase sharply. Furthermore, if no adequate solution is found for the end-of-life treatment of the electronic waste generated by millions of very small components, precious raw materials will be lost and pollutants emitted to the environment.
- Dissipation of responsibility in computer-controlled environments: As a rule, it is not possible to isolate the cause of damages due to the combined effects of several components from computer hardware, programs, and data in networks. As society's dependence on systems of this kind will grow with Pervasive Computing, a net increase in the damage derived from unmastered technical complexity has to be expected.

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