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UBIQUITOUS TRANSPORT SYSTEMS:

Negotiating Context through a Mobile-Stationary Interface

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Ubiquitous computing environments grant organizations a multitude of dynamic digital traces composed of context signals emanating from embedded and mobile components. However, previous research indicates that the utility of context data is frequently hampered by a priori interpretations of context embodied within the acquiring technologies themselves. This paper reports an 18 month action research study seeking to rearrange an industry wide assemblage of stationary, mobile, and embedded technologies and associated organizations for the purpose of facilitating cross-organizational access to reinterpretable digital traces of context data. This was done by embedding the notion of seamfulness in an open standardized interface as a means to shift the locus of interpretation of context data in ubiquitous transport systems. In environments such as these, open access to context data is of essential importance to create opportunities for flexible interpretations of mobile work for uses not anticipated by preconfigured representations. However, this requirement essentially clashed with the business strategies of actors providing context data acquiring technology. This clash resulted in a negotiated design compromise of limited access and a well defined expansion of additional uses of context data between the involved actor groups. Addressing the issue of how organizations can derive value from context data, the contribution of this paper is an analysis of the complexity of accomplishing links between socio-technical elements in ubiquitous computing environments.

1 INTRODUCTION

Following Weiser's vision (1991), the miniaturization of computing devices and improvement in communications have steadily increased. Indeed, the notion of computing "anytime, anywhere" has been evident in the continuous diffusion of mobile and embedded computing for a number of years (Lyytinen and Yoo 2002). Ubiquitous technologies are increasingly appearing outside of laboratories, forcing organizations to adapt their organizing logic to the increased socio-technical complexity of computing environments involving mobile, embedded and stationary elements (Sambamurthy and Zmud 2000). Its integration in distributed organizational settings is becoming increasingly commonplace, enabling studies of real world usage (Andersson and Lindgren 2005; Jonsson and Holmström 2005).

An essential notion in research on ubiquitous computing is context awareness. Context awareness refers to the capability of systems to recognize and adapt to the multifaceted context of their use (Abowd and Mynatt 2000). It is an often stated goal in related research that ubiquitous applications and services should utilize underlying infrastructure to operate seamlessly over many contexts, thus freeing the user from the manual adjustments otherwise required (Dey 2001; Henfridsson and Lindgren 2005). Seamless computing thus refers broadly to the vision of fully transparent unobtrusive computing. A prerequisite for the development of such ubiquitous computing environments are comprehensive infrastructures able to fulfil these demands (March et al. 2000). This requires a unification of a wide variety of technologies and competencies originating from multiple vendors organizations. These organizations will likely have different strategies guiding their conduct influenced by their perceived core competence and installed base of systems and user organizations. In addition, captured contextual parameters are subject to interpretation by various individuals or organizations dependant on their use (Dourish 2004). Given the centrality of organizational knowing in organizations' endeavours to meaningfully acquire and use various pieces of contextual information, deriving value from environmental information should be seen as emerging processes of situated and ongoing relationships of context, activity stream, agency, and structure (Lindgren et al., in review). In attempting to design a seamless environment that delivers their a priori interpretations of context, vendors are effectively omitting this important characteristic.

Addressing this issue, the research presented here utilizes action research (Baskerville and Wood-Harper 1996) to intervene in a real world problem situation. Ubiquitous transport system (UTS) is studied as industry specific instance of ubiquitous computing environments, targeting the needs of road haulage organizations. UTS consists of a multitude of stationary, mobile and embedded technologies utilized by drivers, dispatchers and managers. Contextual representation utilizing sensor technology to deliver data has been found highly problematic. Andersson and Lindgren (2005) provide support for the thesis that mobile systems are not simple conversions of stationary systems into a different environment, but require comprehensive integration between mobile, embedded and stationary components. They also demonstrate the need for organizations to understand and agree on the meaning and value of context information as part of their strategy to integrate highly distributed people and systems. The inflexible utilization of mobile and embedded technologies and the resulting limitations of representations of mobile context in current solutions form the basis of the action reported here. An alternative approach is explored, utilizing the notion of seamfulness (Chalmers and Galani 2004) as a means to counter this interpretational inflexibility of the current seamless "closed pipe" approach to UTS. In practical terms, this was accomplished by engaging in a cooperative design effort to introduce an XML-based mobile-stationary interface into the currently fragmented computing environment, intended to increase user organizations' capacity to interpret context as opposed to relying on a predefined representation as visualized by individual vendors. Addressing the issue of how organizations can derive value from context data, the paper illustrates the complexity of accomplishing links between socio-technical elements in ubiquitous computing environments.

The paper is outlined as follows. First, the notion of ubiquitous computing environment and the associated problem of inflexible interpretations of context data are illustrated. This is followed by a description of UTS and the working hypothesis guiding this research effort. Following a description of the research setting and the method applied findings are presented and discussed.

2 UBIQUITOUS COMPUTING ENVIRONMENTS

The concept of ubiquitous computing environments is increasingly studied in IS literature (Henfridsson and Lindgren 2005; Lyytinen and Yoo 2002). Lyytinen and Yoo (2002 p. 378) describes these emerging environments as "... a heterogeneous assemblage of interconnected technological and organizational elements, which enables the physical and social mobility of computing and communication services between organizational actors both within and across organizational borders". Akin to Weiser's (1991) vision of computing embedded in people's natural movements and interactions with their physical and social environment, Lyytinen and Yoo (2002b, p. 63) recognize that "ubiquitous computing will help organize and mediate social interactions wherever and whenever these situations might occur". Similarly, Grudin (2002) asserts that ubiquitous computing promises to enable efforts to record and archive the digital traces of socio-technical activities and interactions in distributed environments over time for real time or subsequent review or viewing by those not present. Once stored in a repository and shared via networks, digital traces can enhance organizations' understanding and knowing of the contexts in which they act (Jessup and Robey 2002). Indeed, capable of leveraging digital representations of contextual information across time and place through advanced sensor technology, ubiquitous computing can be seen as a critical technology in the realm of distributed organizations.

Evidently ubiquitous computing environments require an extensive infrastructure and thus incorporate a range of associated properties. In practical terms, this infrastructure includes wireless communication technologies, sensors and various computing devices. Beyond the technical, the notion of infrastructure takes into account not only the technologies involved, but also the heterogeneous actors involved in realizing and using it (Star and Ruhleder 1996). An infrastructure is thus essentially a blend of social and technical elements. Reviewing information infrastructure literature, Hanseth and Lyytinen (2004) define three general characteristics of information infrastructures. First, as opposed to a traditional information system, an information infrastructure, such as the Internet, has no specific purpose other than a very general idea of offering information related services to a single or group of communities. However, infrastructures can be designed to support rather more specified purposes (Hanseth and Lundberg 2001). Second, they evolve continuously and unexpectedly since they have no fixed boundaries. The presently available information infrastructure, the installed base, will determine the possibilities for further extensions. In this sense, no information infrastructure is built from scratch. Rather, the installed base restricts the ways in which it can evolve (Star and Ruhleder 1996). Thus, factors other than technical superiority will likely play a crucial part in determining the way in which these environments develop. Third, information infrastructures consist of highly heterogeneous technological and social components with complex dependencies. These must be managed through well defined interfaces between constituent layers. In practical terms standards and gateways bind an information infrastructure together (Hanseth 2001) and changes require the negotiation and translation of interests of many different actors (Hanseth and Monteiro 1997; Yoo et al. 2005).

A central driver for organizational diffusion of ubiquitous technologies is context aware computing. A practical implication of the accelerating spread of embedded technology, such as RFID, is the decreasing cost of data input. In this sense, the expanding pervasiveness of the digital world is rapidly closing the gap to the physical (Fleisch 2002). The related services have some important implications for the design of ubiquitous computing environments. First, utilizing underlying embedded technologies, services in ubiquitous computing environment should be able to dynamically recognise the multifaceted context of their use and take appropriate action when it changes (Dey 2001). Second, services should be able to seamlessly access the underlying infrastructure, attaining the resources

necessary for completing the user's task without the need for user manipulation (Abowd and Mynatt 2000). However, interpreting the data gathered is frequently an ambiguous process, highly dependent on the situation at hand (Dourish 2004). Furthermore, one physical sensor can be utilized by a number of services for equally different purposes. Simply adding more sensors would never entirely eliminate the problem of interpreting complex contexts, since the main issue is the a priori interpretation forming the basis of computational representation of context. Rather than designing ubiquitous computing seamlessly, encapsulating an a priori interpretation of context and hiding the constituent parts from user interaction, a seamful design as proposed by Chalmers et al. (2004) aims at exposing the constituent parts of the ubiquitous computing environment to allow a more comprehensive and user centred interpretation when necessary.

An open large scale ubiquitous computing environment would consist of separate layers performing data adaptation, data aggregation and analysis as well as applications reacting to changes in context. This will ideally create incentives for separate producers of context data, middleware, and applications, enabling organizations to construct a ubiquitous computing environment capable of delivering tailored representations of context, easily changed over time (Banavar et al. 2005). However, in separating these areas of concern, joining the diverse sources of context data will require well defined seams. An environment able to produce such reinterpretable representations of context must be highly malleable in that constituent parts can be dynamically combined to inform the task at hand. In an organizational setting, a ubiquitous computing environment should be able to facilitate a wide range of such tasks, capturing representations of experiences from one context and projecting them to another (Abowd and Mynatt 2000). Depending on context and intended use, services need access to the various constituent technologies of the environment to produce an adequate representation. Research on such context aware computing environments includes prototyping of services in real world settings (Henfridsson and Lindgren 2005; Olsson and Henfridsson 2005) and novel architectures (Banavar et al. 2005; Dey et al. 2001). Using the notion of "context ecosystem", Banavar et al. (2005) focus on the nonexistent division of labour among providers of context aware computing. Vendors generally supply and control both low level data capture hardware and high level analysis software. The resulting situation, which is the focus of this paper, is one in which examples of limited custom solutions exist, but their representations of context are the result of vendors' a priori interpretation encapsulated in services and are thus inflexible in terms of reuse for alternate interpretations. In sum, an ideal ubiquitous computing environment including sources of context data should exhibit a number of qualities pertaining to the locus of interpretation. First, a ubiquitous computing environment must enable the exchange of context information across organizational entities. This requires open standardized models and context data formats. Second, a ubiquitous computing environment must combine data from available computing resources to make context data interpretable and exploitable in multiple uses. Third, to enable dynamic representations of context, a ubiquitous computing environment must access a multiplicity of critical sources of context data from a potentially diverse set of providers. Fourth, a ubiquitous computing environment must be able to dynamically discover and utilize new instances of context data sources. Fifth, a ubiquitous computing environment must allow new kinds of context data to be added. In the following section, ubiquitous transport systems, a specific type of ubiquitous computing environment is explored.

3 UBIQUITOUS TRANSPORT SYSTEMS

UTS can be seen as a case of organization scoped ubiquitous computing environment, intended to meet the requirements of transport organizations (Andersson and Lindgren 2005). A mobile organization generally consists of both mobile field operations and stationary headquarters elements. IT-support therefore contain elements of stationary, mobile as well as embedded computing designed to seamlessly cater to specific needs. The interwoven technological realms are commercial telematics (in-vehicle sensors and communication systems) and stationary coordination and administrative systems. The embedded vehicle technologies serve different purposes for different users. For a driver, services utilize vehicle data to display feedback metrics on the performance of the vehicle raising

awareness regarding for instance fuel consumption. Similarly, the resulting persistent digital traces of mobile fieldwork are used by management as a tool to analyse fleet performance from a distance. The stationary systems are used by dispatchers to coordinate assignments, but also to communicate associated information to drivers using integrated mobile communication technologies. In addition, information from positioning technologies such as GPS facilitates this process and is also offered as a customer service while simultaneously enabling in-vehicle navigation services. Furthermore, computing components such as those described above are vital for the inter-organizational coordination required in the complex interwoven and time critical transport industry. Finally, vendors of embedded technologies collecting data use that data for internal purposes of physical product development and associated services (Jonsson and Holmström 2005). A UTS thus spans multiple inter and intra organizational contexts, each of which has distinct requirements of use.

As stated by Andersson and Lindgren (2005), employing UTS ideally endows the organization with a dynamic repository of context data captured by embedded technologies which combined with representations held by stationary systems creates a digital trace of mobile work. However, utilizing this trace means grappling with a heterogeneous set of technologies and associated organizational actors. More specifically, the vendor domain of UTS has been characterized by a large number of actors with diverse incentives. Effectively, the distinction between vendors of stationary, mobile, and embedded technology is an abstraction and in reality most offer both stationary and mobile elements of UTS, producing a ubiquitous computing environment with multiple parallel infrastructures. As an example, the vendors supplying mobile and embedded technology for capturing vehicle data generally bundle it with stationary analysis software. The representations of mobile work embedded in these seamless arrangements are closed in that one vendor or limited alliance defines the interpretation of a given subset of the digital trace in UTS with little influence from the user organizations. The user organizations in turn must deal with a number of such closed seamless arrangements to acquire comprehensive UTS. This effectively constitutes a mobile-stationary divide, limiting the utilization of mobile, embedded and stationary computing to the context representations envisioned by a fragmented set of suppliers of these technologies (Andersson et al. 2005).

Applying the notion of seamfulness to the domain of UTS suggests creating a more adaptive ubiquitous computing environment in which context aggregation and reinterpretation is enabled through a number of well defined seams. In a complex information infrastructure, these seams can be seen as interfaces between defined layers of the environment. Some examples of existing lower level standardized interfaces applicable to UTS are the fleet management system (<http://www.fms-standard.com>) interface (FMS) to embedded vehicle systems and generic wireless communication protocols. However, earlier research into UTS has clearly shown the need to infuse it with further links, providing user organizations a means to avoid the impenetrable seamless representations embodied in “vertical” solutions from single vendors or limited strategic alliances. In a UTS setting they should ideally tie the mobile and embedded and the stationary technologies and users together (Andersson et al. 2005). Services widely used today includes task allocation and progress communication between drivers and dispatchers and status reports concerning vehicle performance (positioning, fuel consumption etc.) and peripheral equipment (such as temperature sensors, scales etc.). The vendors supplying the source of a certain set of context is generally supplying analysis and interpretation of that data as well. As a consequence, such services are based on the use of context data intended by these vendors and there is little or no possibility to add new sources of context to derive new representations catering additional needs.

The case of UTS thus provides a clear example of the problematic parallel implementations of potentially multi purpose ubiquitous technologies and thus constitutes a viable venue for exploring issues with the realization of ubiquitous computing environment embodying flexible means of interpreting context data. To achieve this, as shown in the previous section, an open ubiquitous computing environment should support a division of labour, in essence separating context data acquisition from analysis. Next, the design requirements developed in the previous section are utilized in the UTS setting. First, as a ubiquitous computing environment must enable the exchange of context

information across organizational entities, this requires open standardized models and context data formats shared by mobile, stationary and embedded technologies in the UTS setting. Second, as ubiquitous computing environment must combine data from available computing resources to make context data interpretable and exploitable in multiple uses the vendors of these different technologies should engage in gaining an intra organizational perspective on the uses of context data. Third, since to enable dynamic representations of context, a ubiquitous computing environment must access a multiplicity of critical sources of context data from a potentially diverse set of providers, access provided should be considered a service. Fourth, as a ubiquitous computing environment must be able to dynamically discover and utilize new instances of context data sources, a means of incorporating a strategy of plug and play is necessary. Fifth, a ubiquitous computing environment must allow new kinds of context data to be added. In UTS the standardized means of delivering context data should provide vendors with easily adopted sets of data and a resulting shortening of new service development times. It is not clear how to realize such a separation of concerns in practice. In particular the consequences for the partaking vendor collective will be profound. Indeed, aligning with other actors whose interests may not be consistent with theirs will influence the companies' internal strategies and operations and ultimately their identities (Yoo et al. 2005). By utilizing the general design requirements in this specific problem situation, this research contributes an analysis of their viability and links the findings with further research opportunities.

4 RESEARCH CONTEXT AND METHOD

This paper reports findings from an 18 (2004-2005) month action research cycle of a three year action research project on UTS. The complexity of real world objects of study, such as UTS, makes action research a viable research method in that it stresses the theoretically guided intervention into a practical problem setting in order to produce new knowledge (Baskerville and Wood-Harper 1996). Furthermore, action research has been proven successful in design driven IS research (Lindgren et al. 2004; Markus et al. 2002). Transport organizations experienced problems of utilizing the combined strengths of stationary, mobile and embedded computing. The diagnose phase revealed a mobile-stationary divide in which interpretation of context data was inherently difficult (Andersson et al. 2005). The client system consisted of 4 stationary business system vendor organizations, 3 mobile systems vendors, 3 embedded systems vendors, researchers, and 15 transport organizations. The project group consisted of representatives responsible for communicating the negotiations and planning of action to their respective organizations.

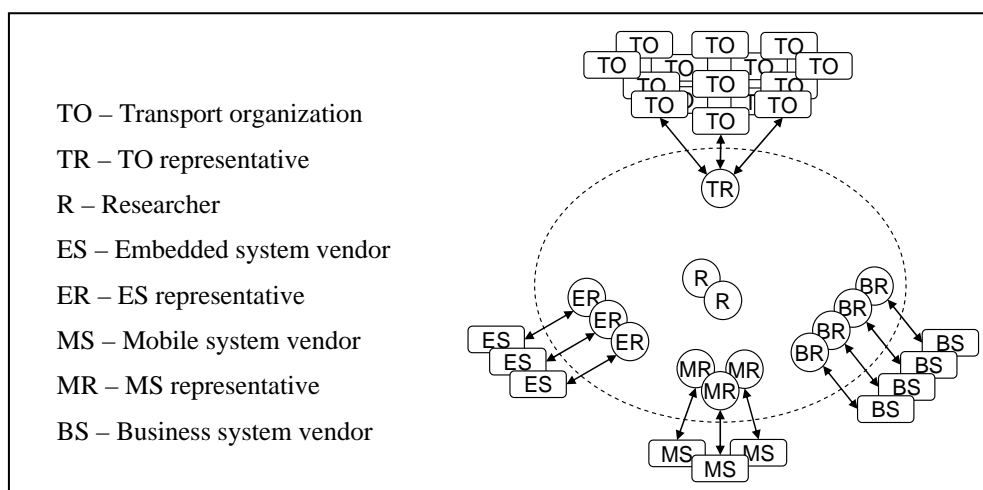


Figure 1: Actors in the client system infrastructure

Guided by the initial diagnose, the action planned was to provide transport organizations with a viable ubiquitous computing environment, enabling them to manage their infrastructure in a way more suited

to the relation between the context aware properties of the technologies involved and their multifaceted use potential. The action taken was guided by the working hypothesis that to rearrange the locus of context interpretation, UTS must provide access to relevant context data in an open format suitable for reinterpretation and exploitability in a wide variety of uses as described in the previous sections. In practice, the seams of the environment were to be manifested in an XML based mobile-stationary interface developed by the researchers residing between the mobile, embedded and stationary components of UTS, aligning the diverse actor groups and enhancing the interpretational flexibility of mobile work processes from the user organizations' point of view. In addition there were immediate practical incentives present for the participating vendors. As vendors of mobile and embedded systems generally managed most of the risk associated with problematic mobile-stationary integrations, a simplified procedure would carry substantial benefits by cutting development and maintenance costs. Incentives were also present for business systems vendors. Historically, business system vendors had with varying success deployed proprietary mobile-stationary interfaces embodying their representations of mobile work. However, they did not utilize data from embedded systems. By simplifying access to such data, a standardized mobile-stationary interface would increase their opportunity for service innovation substantially.

Guided by the theoretical perspective of the proposed intervention developed in the previous sections one of the researchers developed a series of prototype interfaces serving as the basis for the continuous negotiation of the viability of the suggested approach. As the ambition of this project was to restructure the current practice of blending mobile, embedded and stationary systems, success would depend on retaining commitment from the client system. Therefore, all design decisions and implications were to be negotiated in the project group continually providing ample opportunity to follow reactions in the client system. Current proprietary interfaces were utilized as a starting point and the design requirements guided the effort of producing a standardized mobile-stationary interface. In total, 6 iterations of prototyping were performed by one of the researchers. Each prototype was informed by input and evaluative feedback from user representatives and vendors. The resulting prototype interface was then subject to another iteration of feedback and subsequent development. In order to track the reactions from the client system to the prototypes developed these sessions were recorded and subsequently transcribed.

The bulk of the empirical material comes from vendor and user organization interaction in project meetings. Supplemental material consists of conversations captured from a forum for developers, e-mail conversations, and prototype demonstrations for transport organizations. Furthermore, research notes were taken through out the period. During the analysis, the data was examined for statements reflecting participants' reactions to important episodes in order to draw out specific implications for the relationship between the guiding hypothesis and the divergent strategies of the participants (Walsham 1995). Notes taken throughout the study were compared to gain a richer understanding of the interactions utilizing insights gained at later stages. The following section is intended to provide the reader with an understanding of the negotiation of context that took place.

5 EMPIRICAL FINDINGS

The intervention was intended to produce a mobile-stationary interface embedding a flexible approach to the interpretation of mobile work to counter difficulties pertaining to usage of current solutions. By clarifying a division of concerns between mobile, embedded, and stationary vendors as well as user organizations the anticipated outcome was a relocation of the locus of interpretation of the context data utilized in this setting. However, the process revealed a number of highly problematic issues pertaining to the guiding design requirements.

First, as a ubiquitous computing environment must enable the exchange of context information across organizational entities, the initial step of the development process concerned open standardized models and context data formats relevant to the client system. Business system vendors had already deployed proprietary mobile-stationary interfaces embodying their representations of mobile work.

However, though designed to integrate their business systems with mobile systems, they did not utilize data from embedded systems. This profoundly influenced the current scope of mobile stationary integration. In keeping with this, the initial mobile-stationary interface prototypes were thought of merely another interface:

“We’ve got an XML-structure, a schema that is rather similar to this. We have put a lot of effort into it for a number of years. Our view of this is that it is sort of a de facto standard, since we have so many customers running our XML schema already. And this is another variant.”

The vision of UTS proved potent enough to retain the interest of the involved parties. As illustrated by this quote from a business system representative, they gradually came to a greater understanding of the potential of new innovation opportunities gained by standardized access to a published set of mobile context data:

“Of course, some of these operational data types are important to associate with the business system, and tied to individual assignments. GPS coordinates are interesting from a quality perspective. Odometer readings are interesting, perhaps for accounting purposes, when you think you’re not driving the distance you charge for, and quality control so that the driver does not deviate.”

Second, to improve the capacity of user organizations to tailor interpretations of context, the initial prototype included a large number of essentially decontextualized low level vehicle data. This was argued necessary by the user organizations:

“The problem that we have today is that there are two actors who have good access to these systems. What we must strive for is to get more actors who have it.”

Evident in this argument is the belief that open access to context data creates a foundation for innovative uses unconstrained by the currently restricted access. However, vendors of embedded technology became increasingly less enthusiastic about this development, fearing the loss of what they perceived as a proprietary repository of future in-house innovation and business opportunities:

“All of the data that originates from the trucks is always stored in our systems. That is why we get into conflict here. We feel that this information is something that we can make into a unique service. That is something that we are not prepared to give away, we don’t want to leave this business to someone else.”

The ensuing negotiation highlighted the need for explicitly stated uses of context data without which the vendors of embedded systems would not allow access. In order to retain their commitment, an acceptable formula for the division of labour embodied within the interface had to be found. Several prototypes were designed to explore such compromises, and a successful version ultimately rendered access to a subset of vehicle data syntactically coupled to processes of executing and evaluating assignments, leaving low-level data fully to the realm of the vendors of embedded system. This enabled access to the multiplicity of critical sources of context data viewed as necessary by the user organizations.

The ability of a ubiquitous computing environment to dynamically discover and utilize new instances of context data sources was perceived a mixed blessing by the vendors of embedded systems as it would necessitate a shift of focus from complex integration procedures to swift deployment of their products. The mobile-stationary interface was designed to simplify such processes. In spite of a principal agreement to the proposed course of action, as illustrated in this quote from a vendor of embedded technology, there were indications that the simplified integration strived for was not necessarily beneficial from a vendor point of view:

“For a single actor in this mess there are benefits of becoming the best at managing these weird ways [of integration]. Somewhere along the line, we must all decide that this is how we would like to work.”

Essentially, the fragmented market of embedded technologies made the adaptation of new context sources a slow moving, but none the less profitable market for vendors of embedded and mobile

systems. However, this approach also entailed an increasingly untenable maintenance burden as the number of unique integrations grew. This development created the necessary incentive to proceed. As the initial strategy of providing access to low level data had to be modified in subsequent prototyping iterations, the final mobile-stationary interface included representations of context rather more specific than was originally intended. This in turn made future expansions of context data types more complicated than initially envisioned. New kinds of context data would have to be delivered in a standardized format which in turn would require a continuous negotiation process. Regarding the embedded market as highly competitive and volatile, business system vendors feared that such processes would be too cumbersome, thus hindering the successful diffusion of the interface:

“Usually the customer says that we would like to report this field. That means that we have to add a new field to the business system to display and report. That means changes to the standard and that requires management and maintenance and continuous development. I don’t think that the customer will wait for half a year for that field to change, because by then they will have lost their customer. We are solving problems in real time. That means that the standard should change dynamically. Otherwise we are cornered.”

The ability to create representations of mobile work exploitable for multiple purposes was from the onset strongly advocated by user representatives. Though the final prototype only exhibited a limited capacity to increase the interpretational flexibility, transport organizations involved were happy with the result, as illustrated by this quote from the transport organization spokesperson:

“For us, the need is crystal clear. We see this as our chance to be proactive toward our customers, the transport buyers, to be able to sell additional services. Since a transport is a relatively simple service, we want to be able to sell more to our costumers, and we see this as a crucial tool: the vehicle as a data producer that can produce data that is transferred directly into the system without delay.”

It was thus evident from their perspective that the locus of interpretation of viable usages of context data had indeed shifted, just not as radically as was initially intended.

6 DISCUSSION

The utility of existing computing environments including embedded sensor technology is generally hampered by parallel implementations of complementing sets of technologies (Banavar et al. 2005). Without a clear division of labour between suppliers of constituent technologies, the expressiveness of context data will be restricted to representations designed by vendors of the acquiring technology. Simultaneously information infrastructures can not be constructed from scratch. The installed base of mobile, embedded and stationary systems and users has a fundamental influence over its future evolution (Star and Ruhleder 1996). Thus, efforts to realize ubiquitous computing environments requires the negotiation and translation of interests of many different actors (Hanseth and Monteiro 1997). Utilizing this knowledge to actively intervene in a concrete problem situation exhibiting these characteristics, the research reported here adds to the knowledge on ubiquitous computing environments some important insights pertaining to development according to ideal characteristics of a ubiquitous computing environment.

First and foremost, access to context data provided by embedded technology proved a problematic issue. Vendors of embedded technology proved highly protective, partially of their systems, but primarily of the context data they generated. Their repositories of raw context data were seen as potential for in-house innovation and future business. Such commoditization of context data will most likely continue to influence the development of services in ubiquitous computing environments, acting as a counterweight to an envisioned open market context ecology (cf. Banavar et al. 2005). In this case access had to be negotiated through the establishment of specific use contexts and associated services utilizing specific sets of context data. The negotiation of context resulted in a clear prescriptive way of creating exploitable representations specifying combinations of mobile and stationary computing resources. To enable dynamic representations of context, a ubiquitous computing environment must

access a multiplicity of critical sources of context data from a potentially diverse set of providers. However, only a limited set of context data was utilized due to the protective strategies of vendors of embedded technology.

Analogous to the original problem situation, a priori interpretations were the result, but progress was none the less evident as they were a product of a negotiation between the UTS constituents (mobile, embedded and stationary systems vendors, and user organizations), as opposed to determined by the vendors of the data acquiring technology. This implies that the expressiveness of digital traces utilizing context data as perceived by end user organizations will be the result of a negotiation of viable usages, rather than built from readily available low level context data utilized by independent service level actors. In line with prior research, the cost of current solutions was deemed prohibitive by vendors mobile- and embedded systems and user organizations alike (cf. Banavar et al. 2005). Indeed, this remained a potent practical incentive throughout the project. As a ubiquitous computing environment must be able to dynamically discover and utilize new instances of context data sources, an associated strategy of “plug and play” proved a viable incentive for all involved parties. Concurrent with research on large ubiquitous computing environments, the need to transfer context data between organizations was seen as highly important by user organizations. To make this feasible, an XML-based ontology of standardized concepts including context data was negotiated, utilizing existing standards where applicable. The resulting interface was deemed to better cope with a distributed use than the previous proprietary solutions. To summarize, the requirements guiding the design process generated important general insights to research on ubiquitous computing environments. Indeed, the negotiation of context seems imperative to successful implementations of such environments. Open access to context data is of essential importance to create opportunities for flexible interpretations of mobile work for uses not anticipated in original representations. In spite of powerful incentives available, this essentially clashed with the business strategies of the actors supplying the acquiring embedded technology and ultimately resulted in a negotiated compromise of limited access and a well defined expansion of additional uses of context data between the involved actor groups.

7 CONCLUSION

The promises of ubiquitous technologies include narrowing the gap between the domains of material and information and enable context aware computing. However, the establishment of ubiquitous computing environments requires the alignment of a heterogeneous socio-technical assemblage (Lyytinen and Yoo 2002). In doing so, the negotiation and translation of interests of many different actors are essential (Hanseth and Monteiro 1997; Yoo et al. 2005). This paper reports a real world attempt to create a well defined and sustainable link between the installed base of mobile, embedded and stationary technologies in the context of UTS. The design requirements proved useful for initiating change in the practical problem situation as they helped expand the scope of interpretation of combined mobile, embedded and business computing resources through the negotiation of the representations of mobile work. It further highlighted the complexity of governance related to ubiquitous computing environments (Lyytinen and Yoo 2002). In particular, embedded systems were seen not as objective deliverers of context data, but rather as a necessary vehicle for delivering ready made interpretations through end user services. These were based on the preconceptions of the utility of the technologies held by vendors. Thus, rather than committing themselves to the flexible interpretations often cited as an ideal in research (Banavar et al. 2005), a rather more limited increase of flexibility was the result of a finite and well defined expansion of negotiated representations of mobile work. Throughout the process it was clear that there were incentives present for all involved parties. As indicated by March et al. (March et al. 2000) in this highly heterogeneous and competitive environment, the role of the researchers proved essential in providing guidance and support both as a neutral party and as suppliers of a theoretical foundation for the actions taken. As recently stated by Van de Ven (2005), there is a need to theorize innovation in large-scale complex socio-technical systems. Complications presented here pertaining to the positioning of the locus of interpretation of

context data in ubiquitous computing environments indicate that the divergent innovation strategies of divergent organizations involved is a promising venue for further research.

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