Research areas and challenges for mobile information systems

John Krogstie

Norwegian University of Science and Technology,
Institute of Computer and Information Sciences and SINTEF, Norway
E-mail: John.Krogstie@sintef.no

Kalle Lyytinen

Case Western Reserve University, USA
E-mail: kjl13@po.cwru.edu

Andreas Lothe Opdahl

University of Bergen, Norway
E-mail: andreas@ifi.uib.no

Barbara Pernici

Politecnico di Milano, Italy
E-mail: barbara.pernici@polimi.it

Keng Siau

University of Nebraska-Lincoln, USA
E-mail: ksiau@unlnotes.unl.edu

Kari Smolander*

South Carelia Polytechnic, Finland
E-mail: kari.smolander@scp.fi
*Corresponding author

Abstract: This paper explores new challenges and possible approaches for developing mobile information systems, with an emphasis on model-based approaches on the conceptual and logical levels. Over the last few years, we have experienced these new challenges through our involvement in several research and industrial projects on mobile solutions, usability and model-based approaches. We summarise the main challenges of how model-based approaches can support the development of mobile information systems that are to be used together with other types of systems in a primarily professional setting and indicate upcoming research issues in this very dynamic area.

Keywords: modelling; mobile information systems; multi-channel systems.

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Bibliographical notes: John Krogstie has a PhD (1995) and an MSc (1991) in Information Systems, both from the Norwegian University of Science and Technology (NTNU). He is currently a Senior Research Scientist at SINTEF. He is also a (part time) Professor at NTNU. He was employed as a Manager in Accenture, 1991–2000. He is the Norwegian Representative for IFIP TC8 and a member of IFIP WG 8.1 on information systems design and evaluation, where he is the initiator and leader of the task group for mobile information systems. He has published around 50 refereed papers in journals, books and archival proceedings since 1991.

Kalle Lyytinen is Iris S. Wolstein professor Case Western Reserve University in Information Systems and an adjunct professor at the University of Jyväskylä, Finland. He serves currently on the editorial boards of several leading IS journals including*, AIS journal, Information Systems Research, JSIS, Information&Organization, Requirements Engineering Journal,* and *Information Systems Journal*. He has published over 150 scientific papers and conference papers and edited or written eight books on topics related to system design, method engineering, implementation, software risk assessment, computer supported cooperative work, standardization, and ubiquitous computing. He is currently involved in research projects that look at the IT induced innovation in software development, architecture and construction industry, and is developing a high level requirements model for large scale systems. He is also engaged in a project supported by NSF that focuses on the institutional forces involved the development of global electronic commerce. His research interests include information system theories, computer aided system design and method engineering, system failures and risk assessment, computer supported cooperative work, nomadic computing, and the innovation and diffusion of complex technologies and the role of institutions in such processes.

Andreas Lothe Opdahl has a PhD in Computer Science, Norwegian Institute of Technology (NTH), University of Trondheim, December 1992, and a Master of Engineering in Computer Science, Norwegian Institute of Technology (NTH), University of Trondheim, February 1988. From 2000, he has been a Full Professor of Information Science at the University of Bergen (UiB). He is a member of IFIP WG8.1. He has more than 20 refereed papers in journals, books and archival proceedings since 1991, and more than 50 other proceedings, papers, technical reports and teaching materials since 1987.

Barbara Pernici is Full Professor of Computer Engineering at Politecnico di Milano. She is a Doctor in Electrical Engineering (laurea) from Politecnico di Milano and an MS in Computer Science from Stanford University. Previously, she had been Full Professor at the University of Udine (1990–1993) and Associate Professor at Politecnico di Milano (1987–1990). She has published 30 papers in international journals, coedited five books and published about 120 papers at international level. Her research interests include workflow information systems design, cooperative information systems, web-based information systems and virtual enterprises, office and information systems conceptual modelling, computer-based design support tools, reuse of conceptual components, temporal databases and applications of database technology.

Keng Siau is Associate Professor of Management Information Systems (MIS) in the Department of Management, University of Nebraska-Lincoln. He received his PhD from the University of British Columbia. He is a member of IFIP WG8.1 and has published more than 60 refereed journal papers and more than 70 refereed conference papers. He served as the organising and program chair for the International Workshop on Evaluation of Modelling Methods in Systems Analysis and Design (EMMSAD) (1996–2004). He currently serves as the Editor-In-Chief of the *Journal of Database Management*.

Kari Smolander has a PhD (2003) in Computer Science from Lappeenranta University of Technology, lic.econ. (1993) and MSc (1988) in Information Systems from University of Jyväskylä. He has been Senior Lecturer in South Carelia Polytechnic, Imatra, Finland since 1997. He has more than 20 refereed papers in international journals and conference proceedings. In 1990's he was the main architect in the development of MetaEdit CASE tool and the cofounder of MetaCase Consulting. Since then he has worked in industry for several years. Recently, he defended his PhD thesis 'On The Role of Architecture in Systems Development'. His current research interests include architectural aspects of systems development and organizational view on sofware development.

1 Introduction

Today, the PC is only one of many ways to access information resources and services. On the one hand, traditional computing technology is becoming more mobile and ubiquitous [1]; however, traditional mass-media is also becoming richer, as in the case of interactive TV. Whereas information services related to interactive TV are projected to become prominent in a few years, mobility is perhaps the most important *current* market and technological trend within information and communication technology (ICT). This can be attributed to the steadily increasing use of mobile phones equipped with GPRS and GPS, although the development of long-awaited UMTS infrastructures is taking place more slowly than originally envisaged. With the advent of new mobile infrastructures that provide higher bandwidth and constant connection to the network from virtually anywhere, it is predicted that the way people use information resources will be radically transformed.

According to Siau et al. [2], the essence of m-commerce is to reach customers, suppliers and employees regardless of where they are located and to deliver the right information to the right person(s) at the right time. Mobile knowledge workers, who need to access and perform transactions and their work on the information systems of their company and on other systems, are becoming more and more common. To accommodate this shift, a new breed of mobile information systems [3] must be developed. This paper will highlight some of the research challenges in this field that can be related to the conceptual and logical levels of information systems development. Due to the nature of mobile information systems, physical level characteristics also pose new constraints on the upper levels, constraints that need to be taken into consideration.

2 Novel aspects of mobile information systems

Mobile computing systems entail end-user terminals that are easily movable in space, are operable independent of location and typically have wireless access to information resources and services. As in conventional information systems, users share data and are able to perform collaborative work, either synchronously or asynchronously, with other users. The principal characteristic to be studied is mobility and its implications on needed functionalities.

In this section, we will first describe the different aspects of mobility before highlighting the specific aspects of mobile information systems that support the different mobility dimensions. As illustrated later in this paper, mobility is not necessarily only spatial, but is a broader multi-dimensional concept. The goal of each system user (and therefore functionalities) may vary according to the context.

2.1 Dimensions of mobility

Mobility can be *spatial*, *temporal* or *contextual* [4]. The spatial and contextual dimensions are the ones most commonly considered and will therefore be discussed here.

Spatial mobility primarily refers to *people* moving in space and having wireless access to information and services. Secondarily, mobility relates to a variety of things in the environment (parcels, cars, etc.) that may interact with other devices and subsequently influence the people using these devices.

Mobile information systems users are characterised by frequent changes in the context, as given in [5] and listed as follows:

- The *spatio-temporal context* describes aspects related to time and space. It contains attributes like time, location, direction, speed and track.
- The *environment context* captures the entities that surround the user, for example, physical objects, services, temperature, light, humidity, and noise.
- The *personal context* describes the user state. It consists of the physiological and the mental contexts. The physiological context may contain information like pulse, blood pressure and weight, as well as personal abilities and preferences. The mental context may include elements such as mood, expertise, anger, and stress.
- The *task context* describes what the user is doing. The task context may be described with explicit goals or the tasks and task breakdown structures.
- The *social context* describes the social aspects of the user context. It may, for instance, contain information about friends, neighbours, coworkers and relatives. The role that the user plays is an important aspect of the social context. A role may describe the user's status in this role and the tasks that the user may perform. The term *social mobility* [6] refers to the ways in which individuals can move across different social contexts and social roles and still be supported by technology and services.
- The *information context* describes the information space that is available at a given time.

2.2 Differences between mobile and traditional information systems

From an application point of view, mobile information systems differ from more traditional information systems [2,5,7,8]. We have grouped the differences within the following three areas:

- user orientation and personalisation
- technological aspects
- methodology for development and operations.

User orientation and personalisation. Mobile information systems often address a wider user group, which means that user interfaces should feature prominently and early in the design process and often need to be very simple. The resulting user interfaces cannot presume a prior acquaintance with computers, and input and output facilities may be severely restricted (no keyboard, small screen-size, etc.) or based on new modalities (speech recognition, synthesis, etc.). This means that *individualisation* of mobile information systems becomes increasingly important, both at the individual level where user-interface details such as commands and screen layout are tailored to personal preferences and hardware, and the work level where functions are tailored to fit the user's preferred work processes. Individualisation means information systems that both automatically *adapt* themselves to the preferences of the user and that can be explicitly *tailored* by users through a specific user interface. The main goal is to achieve usability of the applications on all possible interfaces, based on adaptation to the different physical devices. Privacy is also an issue that requires a consideration of the amount and time of information that is acceptable for the user in a given context; unsolicited information, for instance, based on the location of the user and his/her profile, may be undesirable for the user and hinder ongoing activities.

Technological aspects including convergence and multi-channel support. Mobile devices have severely limited processing, memory and communication capacities compared to other kinds of computers. Performance considerations, therefore, become increasingly important in the first design steps. Analytically based predictive methods are necessary in order to assess a large number of alternatives during the design of mobile information systems. Mobile information systems also pose new challenges to achieving information systems dependability.

Since the new mobile devices integrate functions that were previously offered by physically separate tools (*convergence technology*), they probably signal the arrival of a plethora of new types of applications. Mobile and other new technologies provide many different ways to offer the same or similar services to customers. For example, broadcast news in the future will be available through traditional television, enhanced television, internet TV, 3G mobile phone and numerous other information appliances (the door of the glove compartment in your car, your living-room wall, etc.). At the same time when new channels to information are provided, existing channels such as traditional PCs over a LAN will still be used in combination with the mobile information systems; therefore, one needs to support a multi-channel approach where the same functionality and information resources are made available across a large range of processing devices.

Methodology for development to ensure organisational return. Mobile information systems are radical and therefore reward an increased focus on idea generation early on in the design process. This also means that there are not always existing services or situations to which problem analysis efforts can be anchored. Another effect of the radically new approaches enabled by technological solutions is that the introduction of mobile information systems often spawns several other initiatives for changing (or related to) information systems.

The mobile clients still develop rapidly, which means that idea generation should not be limited by the technologies that are currently available. It also means that systems must be designed for change. There is little accumulated experience in designing software for the new technologies. As a consequence, lightweight design techniques and early prototyping are the natural choice for practical development projects at the moment. In addition, research is needed on accumulating experience from early development projects and packaging this knowledge into comprehensive, integrated and model-based development methodologies. There is also a need for user-interface guidelines and standards for mobile solutions. While these challenges to traditional software design are not new when seen in isolation, the emerging generation of new information and communication technologies increases their importance because:

- each challenge is *amplified* in the new technologies and
- the new technologies *combine the challenges* in ways that are not yet understood.

3 Background on our structuring of the research area

Our research community has for many years been engaged in the areas of information systems analysis and design methods, their application, evaluation and engineering in general and has followed the development from mainframe to client–server, ERP and web applications. A particular point of interest has been the series of EMMSAD workshops, which has centred on the evaluation of methods. This community has valuable knowledge, skills and experience in the development, teaching and evaluation of methods, particularly as applied to information systems, rather than technical embedded systems. It is on this basis that we address research challenges within mobile information systems.

In our community, a distinction has traditionally been drawn between issues on the conceptual, logical and physical levels:

Conceptual level. At the conceptual level, the information system problems are examined regardless of what part of the current or future information system is (or is to be) supported or automated by information technology. Thus, a conceptual data model, for example, would map how concepts are perceived by people (normally within organisation). This level is also called the essential level.

Logical level. On the logical level, it is taken into account that one is dealing with information technology, but without being overly constrained by the detailed aspects of the concrete implementation technology. Data models on this level, for instance, would take into account the structuring and relationship of data in several relational tables.

Physical level. Finally, at the physical level, all implementation details, such as physical indexes, tablespaces, etc. are considered for use in a database.

We have structured the main research issues and areas in connection to mobile information systems in the same way. For this paper, we focus specifically on aspects of the conceptual and logical levels. Our focus is on the support of model-based approaches. The common approach is to not follow model-based approaches. Although most software engineers are aware of model-based methodologies and many companies claim to base their development processes on them, model-based methodologies are seldom followed in great detail in practice. In fact, in most real software engineering projects, if at all used, semi-formal modelling techniques mainly play a role during the initial development stages. Also, most current multi-channel approaches do not focus on the use of rigorous model-based techniques. The Oxygen Project [9], which was developed at the MIT focuses on the concept of 'pervasive computing' from a technical point of view and introduces a novel network technology in which mobile devices can recognise each other and dynamically configure their interconnection in order to form 'collaborative regions'. Odyssey [10] defines a platform for managing adaptive applications for different mobile devices that use mobile agents.

The Portolano Project [11] investigates the emerging field of invisible computation. It envisions a user interface that combines the data gathered from location sensors, identification tags and online databases in order to determine user intent rather than relying on user commands. In contrast to these projects that focus on automating the support by partly guessing the worker's interests, the Ninja Project [12] aims at developing a software infrastructure for the next generation of internet applications that is more open to adaptation while in use, although not taking full benefit from a model-based approach.

4 Research challenges for mobile information systems

Below, we highlight the main research areas on mobile information systems at the conceptual and logical levels, which are structured according to the three areas described in Section 2.

4.1 Conceptual level

User orientation and personalisation. Traditionally, support for workers performing processes has not been provided. Functions of mobile information system should be tailored to fit the user's preferred work processes, which typically involve other persons. To support teamwork, raising awareness of the status of knowledge resources is increasingly important in a mobile setting. To enhance social mobility, organisations and industries need to develop 'social ontologies', which define the significance of social roles, associated behaviours and context [6]. Given that knowledge resources include both individuals and technology that can be mobile, one should look into interactive systems to improve group performance. Peter Wegner's interaction framework [13] was triggered by the realisation that machines that must interact with users in the problem solving process can solve a larger class of problems than algorithmic systems computing in isolation. The main characteristic of an *interaction machine* is that it can pose questions to human actors (users) during its computation. The problem solving process is no longer just a user providing input to the machine, which then processes the request and provides an answer (output), but, rather, is a multi-step conversation between the user and the machine, each being able to take initiative in the scenario. A major research question in this area is how to specify and utilise interaction machines on a multi-channel platform. Process support technologies are a natural choice for enabling interaction machines. Such technologies are typically based on process models, which need to be available in some form for people to alter them to support their emerging goals. Thus, interactive models should be supported [14,15]. The outset for this thinking is that models can be useful tools in a usage situation, even if the models are changing and incomplete or inconsistent. The user is included as an interpreter and changer of the models, based on underlying interaction machines. Emergent workflow systems [14,16] represent a different approach to static and adaptive workflow systems with respect to their use of models. They target very different kinds of processes; unique, knowledge-intensive processes where the structure emerges or processes with strong requirements for adaptation to the context during process execution. It can be argued that this is not specific for mobile information systems utilising GPRS and UMTS networks, but this area will be even more pronounced in such systems since future information appliances (and a multitude of services across the network) will always be available (and thus more likely to be used in an emergent or ad hoc fashion). Awareness mechanisms are linked to our emergent workflow systems and should be enriched by giving notice of the additional changes in the context.

Approaches such as ServiceFlow [17] point to the need for such flexible solutions, but not to taking a model-based approach. In the EXTERNAL project [18], we have developed a model-based approach that enables the change and adaptation of instance-models by the users themselves. The operating environment is currently available through a traditional web interface using a PC, but we have started to experiment with PDAs as clients.

Methodology for development to ensure organisational return. Siau et al. [2] highlight as an important application-oriented research area the development of m-commerce business models. Within e-commerce, many new business models have appeared. The mobile environment in which m-commerce applications reside will require further adaptations of these models. In order for m-commerce to succeed, it is vital to ensure that all the related applications and services can be accessed with ease and at little cost. Thus, in addition to externalising the business models in the manner of independent computing, it is important to integrate these models with the internal enterprise models and enterprise architecture in order to pinpoint the links to, for example, internal systems for the efficient billing of services provided.

Requirements engineering (RE) of business solutions have so far dealt primarily with the elicitation, specification, validation, management and change of information systems to be accessed through PCs and workstations [3]. As multi-channel solutions, including mobile clients, are developed, additional challenges will arise for those that specify the requirements for these applications. The traditional view of RE [19], where a requirement specification is developed early on in a project and then undergoes only minor changes during development and further system evolution, only partly applies. Rather, it is important to deal with unstable, unclear and inconsistent user requirements that evolve and emerge through actual use.

4.2 Logical level

User orientation and personalisation. The new separation between content and medium found in mobile information systems serves as a major challenge. The design of new systems needs to make a minimum set of assumptions about physical devices in order to provide a maximum level of personalisation. *Personalisation* of mobile information systems becomes increasingly important where user-interface details such as commands and screen layout are tailored to personal preferences and hardware using information about the current context and context trace [20] of the user. Personalisation here means both information systems that automatically *adapt* themselves to the preferences of the user as well as systems that can be explicitly *tailored* by users through a specific user interface. Generally, the context should be explicitly modelled to maintain an overview of, analyse, and simulate the multitude of possibilities open for adapting to the context and the use of context traces. For the more general use of mobile applications, it is also important to be able to adapt these systems to the user at hand, thus making a case for simple user models to guide the adaptation. Banavar and Bernstein [21] highlight the importance of semantic modelling in this respect.

Recently, work within user-interface modelling has focused increasingly on mobile user interfaces [22–24]. This is often done to facilitate some level of common models for the mobile user interfaces and more traditional ones. A central element in this is the development of model-based approaches that are powerful enough to form the basis for the development of user interfaces on the multitude of platforms needed, but still general enough to represent the commonalties in a single place. One approach is to define user-interface patterns with general usability principles as powerful building blocks. Several other researchers have examined how patterns can be used in usability oriented work [25,26] and have described how patterns can fit into all the different phases of a usability engineering life cycle.

A primary challenge for model-based approaches for developing multi-interfaces is to have a set of concepts that are, on the one hand, abstract and general enough to express specifications across a number of very different platforms and, on the other hand, powerful and expressive enough to support mapping to different platforms. Thus, there is a need to combine generalisation and specialisation. A model-based technique that is abstract enough to describe user interfaces with significant differences may run the risk of being banal. By this we mean that the model is not able to describe a sufficient number of aspects of the user interfaces in a way that renders it possible to transform the models into concrete user interfaces without adding so much additional information to the mapping process for each platform that the interfaces may as well have been developed from scratch [27]. A model-based approach for such a system might also prove efficient when needing to run the system on new mobile devices.

Technological aspects including convergence and multi-channel support: There are currently (and will be for the foreseeable future) a multitude of competing technologies available for providing the underlying infrastructure for distributed and mobile applications. A central element when addressing this is the development of model-based specification techniques that are powerful enough to be used as a basis for the development of systems on a large number of technical platforms, but still general enough to represent the commonalties at one place only. The current major initiative within OMG, on Model-driven architectures where both platform-independent and platform-specific modelling notations including refinement techniques are specified, highlights the current industry focus on such an approach. In connection to this, it is interesting to note how meta-modelling techniques and domain-specific modelling (DSM) have found a special application for the design of mobile phone software [28]. It could be argued that mobile information systems are a particularly good climate for using DSM because:

- The software (on the client side) is partly embedded and, thus, needs a higher reliability than traditional software and can be supported by restricting choices through the addition of modelling rules and code generation.
- One needs many very similar variants of the same application.
- There are a number of standards to adhere to, and the technology and standards change rapidly. It may be optimal to define, for example, GSM only once and use this definition in a range of products. Further, it may be useful to plug in, for instance, UMTS or a US analogue system in its place.

Several approaches to customising the presentation of the contents of distributed information systems for different terminal device are reported. A literal translation from the web to wireless is inadequate. Merely squeezing data into small screens detracts from the user experience with mobile devices [29]. Most of the proposals concentrate on the generation of HTML pages for the web and WML pages for WAP. Several automatic transcoding tools have been developed to convert HTML documents into new languages, such as WML or HDML. Nowadays, research interest is devoted to the automatic generation of multi-channel access systems. The most prominent approaches for the development of multi-channel interfaces can be summarised as follows:

- Terminal-independent form management, such as XForms.
- Vocal services such as VoiceXML.
- Common languages such as XHTML Basic.
- Comprehensive multi-channel language for a virtual universal device that includes all the characteristics of the devices through which the developed service should be accessed. CDI-ML and MaxML represent this approach.
- Finally, WebML [30] is a conceptual model for specifying data-intensive websites. WebML includes a structural model to describe data and a hypertext model to describe how data are organised in pages and the navigation among pages. Generative techniques allow sites to be produced automatically even in a multi-channel context; also personalisation facilities are provided.

Model-based development will, in general, be able to support dependability analyses, i.e., the use of methods, techniques and tools for improving and estimating dependability, such as risk analyses, probabilistic safety assessment, testing, formal walkthrough, simulation, animation, exhaustive exploration and formal verification.

Methodology for development to ensure organisational return. Mobile information systems are often radical and therefore reward an increased focus on idea generation early on in the development phase. This also means that services or situations in which to anchor problem analysis efforts such as using As-is analysis as a starting point for To-be design [31] do not always exist. Technology in the field still develops rapidly, which means that idea generation should not be limited by currently available technologies. It also means that systems must be designed for change. Applications of the new technology call for highly distributed systems that comprise new user-interface systems on the client side, new and existing back-end systems, as well as new bridging systems (which port information between other systems). The new technologies, therefore, highlight the need for principled, long-term information system architecture management and for integrating architecture management with software development methodologies. Often there is a need to interface with existing enterprise systems and architectures to enable the new workflow. Another aspect is how to integrate the user-interface models discussed above with other parts of the requirements and design model, for instance, the entity model, process model and goal model. On both the process and the user-interface sides, the challenges can be attacked by extending existing approaches to modelling, although research is needed to investigate the techniques that should be extended and how they could be best adapted to the new problem areas. Looking at the architecture for the general existing mobile information systems framework and solutions (e.g. [32]), we notice that the generic architecture is geared towards the modelling of data, business processes and tasks, events and behaviour, rules, user interfaces and general context information.

5 Research areas and mobility dimensions

In the present section, we focus our attention on the specific issues of research in the mobile information systems areas, comparing them to research areas in information systems design and web information systems design. We briefly discuss the research issues around the mobility dimensions and aspects discussed in the previous sections.

First of all, mobility dimensions can be organised in three (partially overlapping) subsets:

- *Modelling-related (M) aspects*. Some traditional modelling issues need to be revisited for mobile information systems, due a specific need to support different paradigms of activity flows which cannot be forecasted in advance or are highly variable.
- *User-related (U) aspects*. In traditional information systems, users are basically classified in categories of users that access given services. Already in web information systems, the consideration of user context and profile can support a better service. In mobile information systems, the context and characteristics of the user must be considered in detail.
- *Technological* (T) *aspects*. While traditional information systems modelling is performed without considering specific characteristics of available technology, devices, connectivity, bandwidth, security issues and other technological aspects become a critical success factor in the development of mobile information systems.

In Table 1, we illustrate the main research issues in modelling and model-based support in development or in a running system in the areas of traditional information systems development, web information systems development, and mobile information systems development. We show in the table that the main research focus in traditional information systems and in web information systems research work is on conceptual modelling and that the conceptual and logical design are usually strictly related to each other. We advocate that in the mobile system an important issue is the consideration of physical design, as a way to model aspects of the information system that are strictly related to the execution of applications and the delivery of remote information.

Table 1 Context dimensions

			U	*U*	*U*	*U*	*U*			
							T	*T*	*T*	*T*
		M	*M*	*M*						
		Requirements	*Temporal History, time span*	*Task*	*Personal*	*Social*	*Spatial*	*Environmental Bandwidth, noise, connectivity*	*Information*	*Security protection*
IS	*Conceptual*	Requirements developed early	Data analysis	Process modelling	Known profile		–	–	Conceptual modelling	Privacy, firewall
WebIS	*Conceptual*	Navigation	–				UWA	–	Information architecture	Privacy, firewall
	Logical	Presentation	–		Profiling			Browser availability		Privacy, firewall
MobIS	*Conceptual*	Unstable, unclear requirements	Process modelling	Flexible process model	Profiling	Roles, achievement of goals	Position in space	–	Known resources, conversation, interaction	Privacy
	Logical	Design for change	Substitutability	Substitutability	Adapt + explicit tailoring (usability)	Failed goals recovery	Resource dependency	Mapping to many (channel independence)	New transaction management paradigms	Wiretapping, black box use of data
	Physical		Response time improvement	Physical parameter negotiation	Adaptability		Resource availability	Mapping to many (channel dependency, device evolution)	Data allocation/ moving	Loss of device

The research areas indicated in the table are organised around the following context dimensions:

- *model related*: requirements, temporal, task
- *user related*: spatio-temporal, task, personal, social
- *technology related*: spatial, environment, information, security protection.

6 Conclusion and future work

In this paper, we have highlighted research areas for mobile information systems on the conceptual and logical levels. We have focused primarily on the use of modelling and user-oriented tasks and approaches for business, process, requirements and design models. Although our focus is on user-oriented and traditionally 'early' phases of system development, the need for the rapid and continuous development of new releases of a number of different variants results in a higher degree of reuse and integration of models of different natures. A major research question in connection to these areas is to what extent existing modelling techniques that are based on UML, for example, can be applied, when these techniques should be extended and when they need to be replaced altogether due to the changes of the possibilities and limitations of the underlying infrastructure.

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References

1 Lyytinen, K. and Yoo, Y. (2002) 'Issues and challenges in ubiquitous computing', *Communications of the ACM*, December 2002.

2 Siau, K., Lim, Ee-P. and Shen, Z. (2001) 'Mobile commerce: promises, challenges, and research agenda', *Journal of Database Management*, Vol. 12, No. 3, July–September, 2001, pp.4–13.

3 Krogstie, J. (2001) 'Requirement engineering for mobile information systems', *Proceedings of REFSQ'2001*, Interlaken Switzerland, 2001.

4 Kakihara, M. and Sørensen, C. (2001) 'Mobility reconsidered: topological aspects of interaction', in Bjørnestad, S., Moe, R., Mørch, A. and Opdahl, A. (Eds.): *Proc. IRIS24*, Univ of Bergen, Norway, 2001.

5 Krogstie, J., Brandtzæg, P.B., Heim, J. and Opdahl, A.L. (2002) 'Usable m-commerce systems: the need for modeling-based approaches', To be published in Lim, Ee-P. and Siau, K. (Eds.): *Advances in Mobile Commerce Technologies*, IDEA Group Publishing.

6 Lyytinen, K. and Yoo, Y. (2002) 'The next wave of nomadic computing: a research agenda for information systems research', *Information Systems Research*, April 2002.

7 Hirsch, R., Coratella, A., Felder, M. and Rodriguez, E. (2001) 'A framework for analyzing mobile transaction models', *Journal of Database Management*, Vol. 12, No. 3, July–September, 2001.

8 Kvalsøren, G.M., Langeland, P.F., Moe, R.E., Opdahl, A.L., Solberg, J.O., Thornquist, B. and Wikenes, M. (2001) 'Early design of enhanced ETV services', Bjørnestad, I.S., Moe, R.E., Mørch, A.I.og and Opdahl, A.L. red. (Eds.): *Proceedings of IRIS24: The 24th Information Systems Research Seminar in Scandinavia*, Bergen, Norway, Institutt for informasjonsvitenskap, UiB; s, pp.465–478, Ulvik, 11–14, Aug, 2001.

9 Dertouzos *et al*. (1999) 'The future of computing', *Sc. Am.*

10 Noble *et al*. (1997) *Agile Application-Aware Adaptation for Mobility*, 16th SOSP, 1997.

11 Esler *et al*. (1999) 'Data-centric networking for invisible computing: the Portolano project', *5th ACM/IEEE Conf. on Mob. Comp. and Netw.*

12 Fox *et al*. (1998) 'Adapting to network and client variation using active proxies: lessons and perspectives', *IEEE Pers. Comm.*

13 Wegner, P. (1997) 'Why interaction is more powerful than algorithms', *Communications of the ACM*, Vol. 40, No. 5.

14 Jørgensen, H.D. and Carlsen, S. (1999) 'Emergent workflow: integrated planning and performance of process instances', *Proceedings Workflow Management '99*, Münster, Germany.

15 Jørgensen, H.D. (2001) 'Interaction as a framework for flexible workflow modelling', *Proceedings of GROUP 2001*, Boulder, Colorado, October 2001.

16 Colombo, E., Francalanci, M., Mecella, C., Pernici, B. and Plebani, P. (2002) *Cooperative Information Systems in Virtual Districts: The VISPO Approach*, IEEE Data Eng. Bull., Vol. 25, No. 4, pp.36–40.

17 Wetzel, I. and Klischewski, R. (2002) 'Serviceflow beyond workflow? Concepts and architectures for supporting interorganizational service processes', in Pidduck, A.B., Mylopoulos, J., Woo, C.C. and Ozsu, M.T. (Eds.): *Proceedings from CAiSE'14*, Toronto, Canada, 2002.

18 Lillehagen, F., Dehli, E., Fjeld, L., Krogstie, J. and Jørgensen, H.D. (2002) *Active Knowledge Models as a Basis for an Infrastructure for Virtual Enterprise PRO'VE'02 – 3rd IFIP Working Conference on Infrastructures for Virtual Enterprises*, Sesimbra, Portugal, May 2002.

19 Kotonya, G. and Sommerville, I. (1998) *Requirements Engineering: Processes and Techniques*, Wiley.

20 Rahlff, R., Rolfsen, R.K. and Herstad, J. (2001) 'Using personal traces in context space: towards context trace technology', *Springer's Personal and Ubiquitous Computing, Special Issue on Situated Interaction and Context-Aware Computing*, Vol. 5, No. 1, 2001.

21 Banavar, G. and Bernstein, A. (2002) 'Software infrastructure and design challenges for ubiquitous computing', *Communications of the ACM*, Vol. 45, No. 12, pp.92–96, December 2002.

22 Eisenstein, J., Vanderdonckt, J. and Puerta, A. (2001) 'Applying model-based techniques to the development of uis for mobile computers', in *Proceedings of ACM Conference on Intelligent User Interfaces IUI' 2001.*

23 Muller, A., Forbig, P. and Cap, C. (2001) 'Model based user interface design using markup concepts', in *Proceedings of The Eighth Workshop on the Design, Specification and Verification of Interactive Systems*, 2001.

24 Pribeanu, C., Limbourg, Q. and Vanderdonckt, J. (2001) 'Task modelling for context-sensitive user interfaces', in *Proceedings of The Eighth Workshop on the Design, Specification and Verification of Interactive Systems*, 2001.

25 Sutcliffe, A. and Dimitrova, M. (1999) 'Patterns, claims and multimedia', Paper presented at the *INTERACT'99 7th International Conference on Human-Computer Interaction*, Edinburgh, UK, 1999.

26 Welie, M.V. and Trætteberg, H. (2000) 'Interaction patterns in user interfaces', *7th. Pattern Languages of Programs Conference*, Allerton Park Monticello, Illinois, USA, 2000.

27 Nilsson, E.G. (2002) 'Combining compound conceptual user interface components with modeling patterns – a promising direction for model-based cross-platform user interface development', *Proceedings of 9th International Workshop on the Design, Specification and Verification of Interactive Systems*, Rostock, Germany, June 12–14, 2002.

28 Kelly, S. and Tolvanen, J-P. (2001) *Visual Domain-Specific Modelling: Benefits and Experiences of Using Metacase Tools*, Metacase Consulting, 2001.

29 Billsus, D., Brunk, C.A., Evans, C., Gladish, B. and Pazzani, M. (2002) 'Adaptive interfaces for ubiquitous web access', *In Communications of the ACM*, Vol. 45, No. 5, pp.34–38, May 2002.

30 Ceri, S., Fraternali, P., Bangio, B., Comai, S. and Matera, M. (2002) *Designing Data-Intensive Web Applications*, Morgan Kaufmann Publishers, Dec. 2002.

31 Rolland, C. and Prakash, C. (2000) 'Bridging the gap between organisational needs and ERP functionality', *RE Journal*, Vol. 5, No. 3, pp.180–193, Springer, 2000.

32 Celesta Universal mBusiness Platform (2003) (http://www.celesta.com/products.html), March 15.