JYVÄSKYLÄ STUDIES IN COMPUTING
61

Artem Katasonov

Dependability Aspects in the Development and Provision of Location-Based Services

JYVÄSKYLÄN YLIOPISTO

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UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 2006

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ABSTRACT

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Mobile commerce has been predicted a great future and even forecasted to become soon a dominant force in business and society. In turn, location-based services (LBSs) are often named to be one of the most promising m-commerce areas. However, while the LBS market potential is great, there are still significant barriers to overcome, including imperfection and cost of technologies for automatic positioning of user terminals, privacy concerns, and lack of standards. This study tackles dependability of location-based services – an issue that we believe to be a critical success factor for LBSs, and that seems at present to be one more barrier hindering the fulfillment of the LBS business potential. Dependability of a system refers to the ability to deliver service that can justifiably be trusted by its users. In the study, several major dependability aspects are tackled, including LBS content quality, software reliability, appropriateness of algorithms used (including the positioning approach), networking quality (i.e. taking into account restrictions of mobile networks), and user interface quality. The contributions of the study include a conceptual analysis of the LBS dependability issue, and solutions to several problems that were identified as very significant for LBS dependability. The first is the method for assessing the content quality in an LBS, the second is the method for communication of location-dependent data to the LBS users, aiming for joint improvement of interface quality and networking quality, and the third is the framework for the quality control of the system requirements. Also, some practical recommendations are developed with respect to the testing process improvement. The main part of the study was performed in a research project with direct industry participation and concentrated on those issues, unresolved by the scientific community, that the participating companies face in their practice. It is hoped that the study and its findings are useful for all the parties in the LBS business, including mobile operators, content providers, software development companies, and others.

Keywords: location-based service, location-dependent data, mobile computing, m-commerce, dependability, reliability, software quality assurance

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Jyväskylä
March 2006

Artem Katasonov

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CHAPTER 1

INTRODUCTION AND OVERVIEW

1 INTRODUCTION

According to statistics published by the GSM Association (2005), in September 2005 there were 1.56 billion GSM subscribers and 2.03 billion subscribers of mobile networks worldwide. In September 2004, these numbers had been 1.21 billion and 1.61 billion, correspondingly. As can be seen, although already huge, the market is still growing at a fast pace. While being saturated in some developed countries, such as Japan and many countries belonging to the European Union, the markets are still expanding rapidly in China, India, Russia and Latin America.

This presents huge customer potential for commercial activities. At the same time, the development of mobile terminals continues at a fast pace. Most new mobile phones are Java-enabled and can run, in principle, any application with reasonably small resource requirements. The small and light, yet powerful, mobile terminals are carried by their owners almost everywhere and at all times. For these reasons, *mobile commerce*, or *m-commerce*, which is the activity of conducting e-commerce transactions over a wireless network using mobile terminals, has been predicted a great future and even forecasted to become soon a dominant force in business and society (Senn, 2000).

Recent technological advances have also created a possibility for automatically determining the location of a mobile terminal. This important capability enables a wide range of new commercial services in mobile networks, including services for personal information and navigation (yellow pages, route guidance), location-based advertising, finding and tracking services (friends, children, property), and efficient interfaces to physical services (taxi, emergency assistance). The common term used to refer to all these services is *location-based service (LBS)*. The term *location-based mobile commerce*, or *l-commerce*, has also been introduced (e.g. Barnes, 2003).

It is important to notice that the term 'location-based service' is used in the literature both for denoting the actual service, i.e. the behavior of a system as it is perceived by its users, and the system itself. To be precise, the latter should be called 'a system providing a location-based service'. However, to be consistent with the existing literature and for the sake of brevity, we also use the term 'location-based service' to denote both. When necessary, we differentiate between the meanings by using e.g. the term 'LBS system'. Elsewhere, the meaning should be reasonably clear from the context.

The interest in LBSs is, to a great extent, raised by the availability of technologies for automatic positioning of mobile terminals, such as satellite-based GPS (NAVSTAR, 1995), cellular-network-based Cell-ID, TOA, and E-OTD (ETSI, 2001), and WLAN-based technologies(e.g. Davies et al., 2001). Also, the Wireless E911 Rules of the US Federal Communication Commission (FCC) are often seen as the starting point for intensive development of LBSs. The rules required that the location of any mobile phone originating an emergency 911 call can be automatically determined with a certain precision. However, most definitions of LBS do not exclude manual positioning either, i.e. when the user of the service specifies a location by typing a street address or by pointing on a map on the screen. For example, the Finnish Center for Technical Terminology defines a location-based service as "*a value-added service that utilizes the location information provided by the user, or by a positioning device, or by a device that can be positioned*" (Tekniikan Sanastokeskus, 2002).

Location-based services are often named as one of the most promising m-commerce areas. Some authors even present location management as a basic requirement for many different types of m-commerce applications (Varshney and Vetter, 2002; Varshney, 2003). While mobile technologies enable access to information and services "anywhere and anytime", knowledge about the location of a mobile terminal can, among other benefits, enable provision of services that are relevant "right here and right now". Location-based services could profit mobile network operators, geographic data and software vendors, providers of various location-dependent content, and even mobile phone manufacturers since LBSs may require the use of more advanced handsets. LBSs could also become a new channel through which a variety of businesses, such as restaurants, hotels, shops and others, could effectively reach their customers. Pushed forward by all these different players, location-based services have been a hot topic for both researchers and practitioners for a decade already.

According to the forecasts made in 2001, the LBSs should have had over 300 million users by the end of the year 2004 (Singhal et al., 2001), from which figure the current user numbers are still quite far behind. Those forecasts obviously reflected the IT boom at the time. The recession that followed made the mobile operators wary about investing into innovations. However, it is acknowledged also that those few services that were deployed did not become an immediate success. This indicates that, before LBSs could become a commercially successful technology, there are issues that must necessarily be resolved. While the LBS market potential is great, there are significant barriers to overcome (Steinfield, 2004). More recent forecasts (3G Newsroom, 2003) predict the average annual LBS revenues of $12 per GSM subscriber in 2005, and thus more than $12 billion in total worldwide, growing to $35 per subscriber by 2008. However, unlike earlier forecasts, they include an 'only if' statement – only if low cost mass market enabling technologies are in place to drive the market. The question there is about higher precision positioning solutions, given that Cell-ID based services have proved disappointing in terms of application innovation and consumer take-up. However, imperfection of deployed technologies for automatic positioning of user terminals is only one of the problems. Some other well-recognized issues, without resolving which the LBS business potential is unlikely to be seen fulfilled, are privacy concerns, and limited LBS standards.

This dissertation tackles one such important issue – *dependability*, which we believe to be another critical success factor for location-based services. Dependability refers to *the ability to deliver service that can justifiably be trusted* (Avizienis et al., 2004). Although LBS dependability is not discussed much in the literature, some empirical evidence suggest that, e.g., content quality is insufficient in many existing LBSs, which results in delivery of service that users consider untrustworthy (e.g. Kaasinen, 2003), and that unsuccessful usage experience due to an LBS failure easily discourages users from using the service again (Kaasinen, 2005). Also, Herring (2001) argued that when geographic services are offered, in the form of LBSs, to a broad and non-technical audience the need for quality, related to both the data and software, rises even faster than the market opportunities (see also Section 3).

Roughly speaking, the imprecision of the deployed technology for automatic positioning is a factor hindering acceptance of LBSs (see above) because it results in delivery of service that is not trustworthy enough. However, this dissertation concentrates on those LBS dependability aspects which are rather less the direct result of technology imperfection and rather more under the control of the developers and service providers, i.e. related to LBS content, software, requirements and design. The main part of the research work reported in this dissertation was performed in the industry-cooperation research project KOTEVA at the Information Technology Research Institute of the University of Jyväskylä. Our research concentrated on issues, unresolved by the scientific community, that our industry partners face in their practice. The study, as a whole, followed the Information Systems research framework of March and Smith (1995) and Hevner et al. (2004). Given the business need of assuring dependability of location-based services, we attempted both to explain phenomena related to this business need, i.e. analyze LBS dependability issues, and to build artifacts, mainly of the method type, to aid in meeting the business need.

Section 2 of this introductory chapter will discuss dependability and related terms. In Section 3, some argumentation will be presented for the importance of studying LBS dependability, and the main issues will be identified. Section 4 will present a discussion of the relation between location-based services and context-aware systems. Section 5 will comment on the related research. Then, Section 6 will present the research approach, including the research framework, process, and research methods used. In addition to this opening chapter, the dissertation consists of eight articles. An overview of the articles will be presented in Section 7. Finally, Section 8 will present conclusions and future work directions.

2 DEPENDABILITY OF COMPUTER-BASED SYSTEMS

Dependability is recognized as an important concern for any kind of computer-based, and in particular software-intensive, systems. This section introduces dependability and related terms, using definitions from the article of Avizienis et al. (2004), which is the most recent overview of the basic concepts of the dependable computing field to its present stage of development. Even while the literature uses the term dependability quite consistently, the term is rather general and its connection to related terms such as reliability, security, usability, etc. is not precisely defined. Also, an issue for which a consensus has not yet emerged concerns the measures of dependability (Avizienis et al., 2004).

The basic definition of dependability, to which this dissertation subscribes, is *the ability to deliver service that can justifiably be trusted*.

The *service* delivered by a system is its behavior as it is perceived by its *users*, which can be humans or other systems. The service is supposed to implement the intended system *function*, and if it does, it is called the *correct service*. Service delivery takes place at the *service interface*, which is a part of the system boundary. The part of the system's total state perceivable at the service interface is its *external state*, while the remaining part is its *internal state*. Therefore, the delivered service could be seen as a sequence of external states. In many systems, the service delivered is a sequence of discrete servicing sessions rather than a continuous process. A session may be triggered by either an explicit user's request or when a condition is fulfilled. The first approach leads to the traditional "request-response" type of services, often referred to as 'pull' services. The second approach leads to the so-called 'push' services.

An event that occurs when the delivered service deviates from the correct service is called a service failure, or just *failure*. The failures are classified into *content failures*, denoting deviations in information content at the service interface, and *timing failures*, denoting deviations in time of arrival or the duration of the information at the service interface. Failures when both content and timing are incorrect fall into two classes: *halt failures*, when the service is halted, e.g. in the case of a crash (perceived as e.g. when there is no response at all to a request), and *erratic failures*, otherwise.

The part of the total run-time state of the system that may lead to its subsequent service failure is called an *error*. Errors appear usually first in the internal state of the system, but then they may propagate causing other errors, finally reaching the service interface and thus causing a failure to occur. The adjudged or hypothesized cause of an error is called a *fault*. Avizienis et al. provide the taxonomy of faults based on eight binary dimensions: development and operational, internal and external, natural and human-made, hardware and software, malicious and non-malicious, deliberate and non-deliberate, accidental and due to incompetence, permanent and transient. Therefore, faults may be, e.g., incorrect program code (development internal human-made), mistakes of human users (operational external human-made), or natural disasters (operational external natural). So-called bugs, defects, and even attacks – are all some special cases of faults.

There exist several commonly used system attributes, which dependability is considered to be encompassing. Avizienis et al. include the following list of attributes. *Availability* is readiness for delivery of correct service; it is usually measured as the percentage of time when the system is operational. *Reliability*, which is closely related to availability, refers to the continuity of correct service; it is usually measured as the mean time to failure (MTTF). In systems, where the service delivered is a sequence of discrete servicing sessions, e.g. request-response pairs, MTTF can also be treated as the mean number of correct sessions before a failure. Software reliability engineering (SRE) methodology of Musa (1998) takes this approach. Musa presents this as measuring time in "natural units" of execution instances. Thus, the reliability can also be interpreted as the probability of receiving the correct service in any given session, e.g. the correct response to a query.

Safety is the absence of catastrophic consequences on the users and the environment, i.e. safety is reliability with respect to a class of failures considered to be catastrophic. *Integrity* is the absence of improper system alterations and *maintainability* is the ability to undergo proper modifications and repairs; these two attributes do not seem to have measures defined. Earlier works (e.g. Laprie, 1992) included also *security* as a dependability constituent. However, its relation was unclear and Avizienis et al. (note that J.C. Laprie is among the authors) describe security as a related yet separate concept. Security, similar to dependability, aims for integrity and availability, specifically concentrating on preventing malicious faults; and it also has one more goal – confidentiality, which is the absence of unauthorized disclosure of information.

Dependability, however, is not just the sum of the attributes described above. There is a significant difference. For measuring an attribute such as reliability, one only needs to have a definition of what constitutes the correct service of the system and what is therefore a failure. But for measuring dependability, one also needs to know how much the users of the system are dependent on its service. As the definition above states, the system is dependable when the service it delivers is trustworthy. Avizienis et al. define *trust* as accepted dependence. In turn, they define *dependence* of system A (the user) on system B as the extent to which the system A's dependability is (or would be) affected by that of the system B, i.e. whether and to what extent failures of B may lead to subsequent failures of A. Dependence can vary from *total dependence*, when any failure in B causes A to fail as well, to *complete independence*, when B cannot cause A to fail. Therefore, roughly speaking, a system is dependable when the service delivered by it suffices for the dependence being placed on it by its users.

Avizienis et al. note that if there is reason to believe that B's dependability will be insufficient for A, there are three possible ways to correct the situation: improving B, reducing dependence of A on B, or implementing in A some additional means of fault tolerance. *Fault tolerance* is aimed at failure avoidance and carried out via error detection and system recovery. Avizienis et al. also note that the extent to which A fails to provide means for tolerating B's failures is actually a measure of A's (perhaps unthinking or unwilling) trust in B.

Dependability, therefore, is not really an attribute of the system alone. It is rather an attribute of the system in the context of its interaction with a particular user type. This makes dependability similar to the concept of *quality*, which is often described as the fitness for the intended use. Quality is a concept broader than dependability, however. It encompasses also *utility* that, roughly speaking, describes how much the users of the system could benefit from the service provided (given that it is trustworthy).

In addition to the definition of dependability presented above, Avizienis et al. provide a reformulation, which describes dependability as the ability to avoid service failures that are more frequent and more severe than is acceptable by the users. The goal of this reformulation of the definition is to stress the claim that dependability is nevertheless a quantitative concept, even while a consensus has not yet emerged concerning the measures of it as a whole.

We believe that the measures of dependability will eventually be defined. However, it does not seem that achieving the ability to describe the dependability of a system with a single number is a major issue in the area. This is probably because the main value of the dependability concept is that it provides a starting point for the conceptual analysis of a system. Analyzing the system from the dependability perspective, one gets into thinking about possible failures and their impact on the users, about what reliability or availability levels will be required, and about what are the faults that can cause the most critical or the most frequent failures. In practice, the faults are what is finally treated. According to Avizienis et al., the four basic means to attain dependability are fault prevention, fault tolerance, fault removal and fault forecasting.

In the present study, we also used the dependability and other concepts presented in this section as a conceptual framework for analysis of our objects of interest, location-based services. In its later stages, the work concentrated on some specific types of faults that we identified as posing major threats to the dependability of LBSs.

It is notable that Avizienis et al. mention *usability* as an important system property that affects dependability. ISO 9241-11 (1998) defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. *Effectiveness* is the accuracy and completeness with which users achieve certain goals, *efficiency* is the relation between accuracy and completeness and resources (mainly meaning time) expended in achieving them, and *satisfaction* is the users' comfort with and positive attitudes towards the use of the system. Thus, usability is a very broad property; however, usability research in computer-based systems traditionally concentrated mainly on issues related to the design of user interfaces. Avizienis et al. do not discuss the relation between dependability and usability to any extent; however, in the list of the challenges in dependability research, they state that the problems of complex human-machine interactions (including user interfaces) remain a challenge that is becoming very critical, and that the means to improve their dependability and security need to be identified and incorporated.

An earlier work shedding some light on the relation between dependability and usability is that of Maxion and deChambeau (1995). The authors discussed what they called "dependability at the user interface". They argued that even if a system's hardware and software underpinnings are completely reliable, errors at the user interface can cripple or destroy a mission, often with catastrophic consequences. They made a reference to Goldberg (1975), who first introduced the concept of "fool tolerance" as a desired feature of user interfaces and identified at least two cases when it is required: a user misinterpreting an instruction on the screen proceeds in a wrong direction, and a user disbelieving what he sees initiates an inappropriate action. Clearly, the users are not "fools" in these situations, but rather the user interface should be blamed for not matching their mental models. Maxion and deChambeau discussed many more types of interface defects. They proposed that any aspect of a user interface that impairs a user's ability to achieve a goal, or affects the speed or accuracy of achieving it, should be considered to be a dependability defect. On the other hand, cosmetic aspects of user interfaces may or may not be appealing to users, but unless they pointedly inhibit successful task completion, they should not be seen as dependability defects.

This dissertation subscribes to this view of Maxion and deChambeau (1995). Any aspect of a user interface, or any other aspect of a computer-based system traditionally studied as usability-related, e.g. data visualization technique used, given that it pointedly affects effectiveness or efficiency of achieving user's intended goals, is considered to be falling under the dependability definition. In other words, those impairing aspects are considered to be faults, and impairments in effectiveness or efficiency caused by them to be service failures.

3 DEPENDABILITY OF LBS SYSTEMS

As discussed in Section 2, dependability is a well-recognized and important concern for any kind of computer-based systems. Therefore, dependability is clearly of importance in a case of a location-based service, as it is in a case of any other service delivered by a computer-based system. Also, an extensive body of scientific and practical knowledge gained on assuring computer-based systems' dependability, related to all the constituent activities - fault prevention, fault tolerance, fault removal and fault forecasting - is readily available for applying to LBS systems.

We believe, however, that dependability in location-based services is an issue deserving separate attention.

First, LBSs like any new technology present a set of specific dependability-related problems. This is consistent with Avizienis et al. (2004), who state, in the list of the challenges for dependability research, that new technologies and new concepts of man-machine systems (ambient computing, nomadic computing, grid computing, etc.) will require continued attention to their specific dependability issues.

Second, we believe that dependability is a critical success factor for location-based services, and at the same time it is quite difficult to achieve. This is something that makes LBSs different from most other types of mobile services. Of course, extensive empirical evidence would be required to prove this point. We can only provide the following arguments.

The majority of LBS systems are in fact what we prefer to call *ubiquitous decision support systems (UbiDSS)*. We could define a UbiDSS as a computer-based system that aids the user in judgment and choice activities in his/her interaction with his/her immediate physical environment. UbiDSS is our own term. The term closest to it that can be found in the published literature is probably "mobile guide", referring to applications *guiding* mobile people (Cheverst and Schmidt-Belz, 2005). However, that term implies rather passive users, and, therefore, is not probably the best one.

The term "decision support system (DSS)" is widely used in the Information Systems literature, and the concept of DSS is extremely broad

(Druzdzel and Flynn, 2003). Druzdzel and Flynn define DSS as interactive computer-based systems that aid users in judgment and choice activities. Power (2002) describes DSS as interactive computer-based systems that help people use computer communications, data, documents, knowledge, and models to solve problems and make decisions. Finlay (1994) simply puts that a DSS is a computer-based system that aids the process of decision making. Therefore, assuming that the information, recommendations or another service that LBSs provide are mainly aimed to aid people in making some decisions, about where to go, which road to take, when to go, whether to go at all, where to call, etc., there seems to be very little problem with considering LBSs to be a subclass of DSS.

A special feature of LBSs when compared with traditional decision-support systems is their ubiquitousness. Here, the word "ubiquitous" is mainly used in its dictionary meaning "present or appearing everywhere; omnipresent" (OED, 1989). Therefore, *ubiquitous decision support* is decision support available anywhere and anytime, as contrasted to that available only for a user in front of a PC. It is also decision support on a variety of real-life problems, as contrasted to support in solving some special management problems. The value of ubiquitous decision support is obviously also in its being *just-in-time* decision support (e.g. as in Davenport and Glaser, 2002). The information needed for decision making is delivered just when and where it is needed, thus reducing the need for preplanning, increasing the user's acting flexibility, and providing assistance in unexpected situations. The word "ubiquitous" is selected also as a link to the concept of ubiquitous computing (Weiser, 1993), to which LBSs are usually seen as related. Ubiquitous computing refers to the vision of computers integrated with the physical environment and being tools *through* which people work and thus disappearing from their awareness, as contrasted to traditional computing, where computers are isolated entities being the focus of attention and being tools *with* which people work.

Of course, LBS is not the only type of system that can be considered to be UbiDSS. This will be discussed in Section 4.

If one agrees that an LBS system is an UbiDSS, it becomes apparent that, as any DSS, LBSs may have a negative impact on the user when the information or recommendations they provide are erroneous. Moreover, ubiquitous just-in-time decision support significantly raises the probability that a service failure will result in a user failure, i.e. a situation where the user commits an action that he/she will later consider as wrong. Even a small error in information may turn out to be very significant when this information is used real-time for making immediate decisions. In terms of Section 2, one may say that the nature of an LBS gives the user very little possibility for tolerating service failures, and therefore the dependence of the user on the service may even be near the total dependence.

A nice ironic twist can be found in Herring (2001, p.323):

> The State of New York is considering, as this is being written, a law that would forbid the use of cell phones in moving automobiles. I have seen first hand that

> drivers speaking on a cell phone can cause, and I understand the New York legislature and governor wanting to curtail this source of danger in the heavy traffic of New York City. I just wonder what kind of distraction a few hundred malfunctioning car navigation systems might cause.

Location-based services delivered in mobile networks are unlikely to be as safety-critical as integrated car navigation systems can be in certain circumstances. Of course, some worst-case scenarios are possible with even lethal consequences, e.g. a critical failure in an emergency assistance service. But the most likely negative consequences of LBS failures are wasted time, extra walking distance or wasted gasoline. However, we believe that experiencing even such consequences are more than enough for a user to avoid using the service ever again. The fact that LBSs are commercial applications, which need yet to gain users' acceptance, intensifies the problem. The users are unlikely to be willing to pay for use of something that may potentially cause them to make a bad decision and, as a result, lose time or lead to some even worse consequences.

> When we multiply the causal user problems by their numbers, we begin to get a better idea of the impact. When either user [a casual one or a professional whose failures may have catastrophic nature] gets an answer that is wrong, they will both go somewhere else next time. The result is the same; the supplier of the service loses customers and revenue (Herring, 2001, p.324).

An interesting observation is made in Kaasinen (2005). Obviously, LBSs are services that are used occasionally, rather than regularly. In a series of field studies, Kaasinen observed that users seem to set even higher service reliability requirements for occasionally used services than they do for more frequently used services. As she reports, at times the service entity did not work in an occasional situation where it would have been very useful to the user, e.g. when searching for nearby hotels after a car breakdown in the middle of the night. These kinds of unsuccessful usage experiences discouraged the users from using the service again.

Therefore, we believe that dependability is a very critical success factor in location-based services. At the same time, achieving dependability for an LBS system is not a trivial problem. As said above, the just-in-time approach leaves the user very little leeway for tolerating service failures. Moreover, an average user is usually not prepared for doing that, due to lack of special technical knowledge and experience.

> I can forgive the extra kilometer walk (luckily it was on Sunday and I was not late for anything). Knowing the potential sources of error enabled me to make decisions on the reliability of the data I was getting. This will not be the case with average users, who might actually believe 100% in what they are told, until the second time it fails them (Herring, 2001, p.323).

A continuation of this discussion on the importance of close attention to the LBS dependability can be found in Chapter 3.

The discussion above attempted to justify the claim that *assuring dependability of location-based services* is a business need that forms a problem to be addressed in the research. According to the Information Systems research framework, which will be explained in Section 6, the research attempts both to explain phenomena related to the business need, and to build artifacts to aid in meeting the business need. Similarly, the goal of the present dissertation was to analyze LBS dependability and its aspects, and to develop some solutions to aid in assuring dependability of location-based services. To be consistent with the scientific tradition, these sub-goals may be also represented with a single research question:

> *What techniques, means or processes are needed to assure and improve the dependability of location-based services?*

As mentioned in Section 1, the present study put the emphasis on LBS dependability aspects, which are not the direct result of the imperfection of the present technology but influenced by the control of the developers and service providers. Therefore, we concentrated on *development faults* (as contrasted to the operational ones, see Section 2). As Avizienis et al. (2004) describe, during the development phase of the life cycle of a system, the system interacts with the development environment and various development faults may be introduced into the system by the environment. The development phase includes all the activities from the presentation of the initial concept to the decision that the system has passed all acceptance tests and is ready to deliver service in its use environment. Avizienis et al. also say that, in addition to the faults introduced during the system development, development faults include also the faults occurring during maintenance in the use phase.

The initial part of the study, in which we analyzed location-based services with respect to their general requirements (Chapter 2) and then continued with the analysis of dependability specifically (Chapter 3), resulted in the identification of five major types of development faults that pose threats to LBS dependability.

First, *data*, or *content,* is of paramount importance in LBSs since data is the core of the LBS service provision, it is delivered as such to the users and/or analyzed for generating decision propositions, e.g. routes. Therefore, if the data contain various faults, like inaccuracies, omissions, objects that do not exist anymore and so on, those faults are very likely to translate into some user-perceivable service failures.

Second, s*oftware* is a traditional concern and container of faults in computer-based systems. Therefore, the quality of software, both on the server and on the client side (if any), is another major factor affecting LBS dependability. Software faults are often casually referred to as bugs.

Third, the *algorithmic or technological solutions* that a particular LBS utilizes for acquiring real-time data and analyzing data may actually be inappropriate, e.g. too imprecise, for the purpose of this particular type of service. An example of an acquiring algorithm is the utilized technique for automatic positioning of mobile terminals – the accuracy of it may be sufficient or insufficient, depending on the service type (as discussed e.g. in Varshney, 2003, Barnes, 2003). An example of an analyzing algorithm is how the calculation of the distance between two locations is made – the simplest way is the Euclidean straight-line but, for some applications, the road network must be taken into account (e.g. Papadias et al., 2003). When an algorithm implemented into the system is too imprecise for the service purpose, this can be considered as a design fault, and will cause, with some probability, delivery of service that will be a failure from the user's point of view. Such design faults are as a rule introduced into a system because the requirements, based on which the system is designed, are not of sufficient quality. The requirements, as stated, may be either incomplete – omitting certain non-functional requirements (as it is common in practice), e.g. the required level of the positioning precision – or just be partially incorrect. In other words, such faults as inappropriate algorithms in an LBS are in fact requirements faults. Assuring and controlling the quality of stated requirements during the early stages of the development process is, therefore, the main tool for reducing the probability of introducing such faults.

Fourth, LBSs as any mobile applications may suffer from design faults of not taking properly into account mobile *networking* properties (bandwidth, latency, disconnections). Such faults may result, in certain situations, in service timing failures, i.e. when the response to a request arrives too late to be useful or to impair the efficiency of achieving intended user's goals, or in a failure to deliver any response at all.

Fifth, *interface* is another traditional concern in computer-based systems. As was discussed in Section 2, interface problems may affect both the effectiveness and efficiency of achieving user's intended goals, even inhibit successful task completion, and therefore can be considered to be design faults affecting the system dependability. In LBSs, as in any mobile applications, achieving sufficient "dependability at the interface" (see Section 2) is complicated by various limitations of mobile devices, such as the screen size and limited input capabilities. Also, the mobile users have less "mental bandwidth" capacity for absorbing and processing content – than a stationary user in front of a PC since the interaction with the mobile phone often is reduced to a secondary task that must not interfere with their primary task, e.g., driving or walking (Chincholle et al., 2002). Note that in LBSs a large part of interface issues are related to the visualization of location-dependent data and user interaction with it.

In the rest of the study, we tackled those five areas above separately. As mentioned in Section 1, our research goal was to approach those issues, unresolved by the scientific community, that our industry partners face in their practice. Instead of a superficial analysis, we concentrated within each area on one issue that was identified as the most beneficial, from the point of view of the industry partners.

The part of the study concentrating on the content faults resulted in three articles included as Chapter 4, Chapter 5 and Chapter 6 in this dissertation. The networking and interface parts, at the end, were merged and resulted in the article included as Chapter 7.

The parts of the study that concentrated on the requirements faults and the faults in software resulted in the articles included as, correspondingly, Chapter 8 and Chapter 9. Those two parts have not actually elaborated on problems specific for location-based services. The findings are relevant to the development of any computer-based systems, including LBSs.

4 LBS AND CONTEXT-AWARENESS

LBS is not the only type of system that can be considered to be a ubiquitous decision support system. From one point of view, spatial location is just one of the attributes, describing the world outside the computer system, that might be a part of the very definition of the intended function of that system, or be otherwise relevant. With respect to mobile computing, in addition to location, some other attributes commonly considered are time (time of the day, date, season), activity of the user (standing or walking, talking), the user's physiological measurements (heart rate, blood pressure), social situation (people that are nearby), and environmental measurements (temperature, noise level). Applications that can provide ubiquitous decision support without using any location information are possible. An example is a system that monitors some physiological parameters of the user and provides him with some recommendations when those parameters deviate from the norm.

In the research area of *context-aware computing*, location and other attributes listed above are seen as parameters of the *context* in which an application is run. Becker and Nicklas (2004) define context as the information that can be used to characterize the situation of an entity (including its identity), such as a person, a location, or an object, which is considered to be relevant for the behavior of an application. A context model can be based on both facts and system assumptions (Petrelli et al., 2001). Facts may be collected with the help of sensors (e.g. one determining user's location) or requested directly from the user. System assumptions are either fixed during design of the application or dynamically computed in run time based on the available facts. An important part of the context is identity and other attributes of the user currently interacting with the application. These attributes may include long-term properties of the user (personal traits, knowledge, interests), current state of the user (cognitive load, current goal, emotional arousal), and features of the current user situation (Jameson, 2001). Jameson (2001) also points out that this kind of information can be attempted to be derived partially from data collected through various context sensors (including a location sensor and physiological sensors), and also from the user's behavior with the application.

Location-based services are often regarded as a subclass of context-aware systems. In our opinion, this is not exactly true, however.

A pioneering article in the area, Schilit et al. (1994), introduced context-aware systems as systems that *adapt* according to the location of use, nearby people, hosts, and accessible devices, as well as to changes to such things over time. A recent article by Becker and Nicklas (2004) stated that an application is context-aware if it *adapts* its behavior depending on the context. Also Dourish (2004) describes context-aware computing as a study of how sensor technologies can allow computational systems to be sensitive and responsive to the settings in which they are used, so that, as we move from one physical or social setting to another, our computational devices can be *attuned* to these variations. We could interpret this as meaning that the systems considered here would have some meaningful behavior even without being context-aware, the use of context information by those systems is providing some *additional* benefits.

Dourish (2004) states explicitly that context can be seen as information of *middling* relevance – neither directly relevant nor directly irrelevant to the behavior of the system. Dourish compares this to a conversation between two persons. There are some topics that form the immediate subject of conversation and therefore very relevant, and there are some topics that are completely irrelevant. Neither of those could be normally described as "context". Contextual matters are those that have a general bearing on the conversation assisting in its flow and construction – and include e.g. these conversants' shared history of interaction, location where the conversation takes place (unless they speak about the location itself), people around, and so forth. The main point of Dourish is that context and activity (behavior of the system) cannot be separated: context is not a stable external description of the settings in which activity takes place but, instead, context arises from and is sustained by the activity itself.

As a result, the status of any of the attributes describing the world outside a computer system is not predefined by the nature of that attribute alone. Depending on the application, the same attribute can be irrelevant, be of a direct relevance, or be a part of the context. Obviously, it does not make sense to call a nuclear plant control system a context-aware system – it does use information coming from various sensors to monitor the state of the reactor, but that is its main function. We also believe that it is not appropriate to call a car navigation system context-aware. It does not "adapt" its behavior depending on the location of the car. Location is its major input parameter, i.e. a part of the "subject" (similarly to the subject of a conversation) rather than of the context. Without intending to define yet another new term, in the scope of this section we will refer to such systems as *sensing-based systems* to differentiate them from context-aware ones.

Similarly to car navigation systems, for most LBSs the location of the user is not a part of the context: these systems are "based" on the location information, it is a part of the very definition of their services. Of course, there are also systems for which the location is not of a central importance and can be seen as a part of the context. Such systems can be properly referred to as *location-aware*. Unfortunately, location-based and location-aware systems are seldom distinguished in literature. We believe, however, that the difference is important. LBSs is a subclass of sensing-based systems, while location-aware systems form a subclass of context-aware systems.

The exemplar system mentioned above, which monitors physiological parameters and provides the user with some recommendations based on those, should not probably be called context-aware either. The physiological state of the user is the very subject of that system, not a part of its context. It seems to us that a system could be rightfully considered to be a UbiDSS only if it were really "based" on some attributes of the external world, i.e. were sensing-based, not just "aware" of those attributes, i.e. context-aware. The literature does not seem to discuss such systems much (apart from LBSs), and our example is one of the very few we personally could think about. If a system could accurately know about the user's present activity and goal and provide some decision support based on that, that system would probably fit the description proffered. However, such knowledge could hardly be inferred based on data coming from the available sensors, and therefore the possibility of such systems remains mainly theoretical.

One reason for a somewhat special role of the location parameter is probably the following. It is obvious that future decisions of a user can depend on a variety of parameters describing his situation, among them those listed in the beginning of this section. However, the spatial location of the user is usually the only parameter that is a result of the deliberate action of that user, i.e. his past decisions. The time is obviously important, but people can not control it. Similarly, a person usually does not have direct control over environmental, physiological, or even social parameters. Whether the user is walking or standing is a deliberate action, but this kind of activity is rather short-term, so little can be inferred based on that. On the other hand, the location of a person allows at least some assumptions to be made about the activities and goals of that person. Therefore, even in context-aware systems, the location is the parameter that is considered first and foremost and the location is often used as an approximation of a more complex context (Schmidt et al., 1999).

A strong link between the location and the decision process is demonstrated in a few studies on how people communicate their locations in mobile phone conversations. Arminen (2005) argues that informing the listener about one's location is an extremely common, possibly the predominant practice in mobile calls. In their study, 62 out of 74 mobile calls they recorded involved a sequence in which a mobile caller stated his or her location to the other party. Only in 15% of those calls, the location was used to report on the interactional availability ("I cannot speak because I am in…"). Arminen concludes that such kind of location telling is in fact not as common as one might expect on the basis of the stereotypical images of mobile talk. In 6% of calls, location was communicated as just a social fact. The important thing is that in the remaining 79% of calls location telling had a direct link with decision making process. In 48% of calls the location was communicated as a precursor for an activity (e.g. planning a meeting), in 22% of calls as a part of an ongoing activity (e.g. asking for driving directions), and in 9% as an indirect reference to an activity (e.g. in order to lure the other party to join in). Also, in a study of Barkhuus (2003) the users ranked the locations of both communicators as the second most important context measure (the first is the identity of the other party).

The existence of such a link between the location and the decision making process in human-to-human communications is a good indicator of the potential need for LBSs. Ideas related to some potential services arise directly from the communication practices discussed with the help of the examples above. Instead of calling and asking for directions, a navigation LBS can be utilized; a "find friend" service can help with planning a meeting, and so on.

In conclusion, the spatial location of a person is an important parameter in his or her decision making process. It is deliberately controllable and is therefore a result of past decisions (so that other parties are able to make some logical inferences). It also affects many future decisions of that person, both short-term (related to ongoing activities) and longer-term (planning future activities). Therefore, location-*based* systems make sense. Other user parameters that can be determined with the present sensor technologies do not seem to have such broad and critical importance. Therefore, those parameters are utilized mainly as context parameters to extend the basic functionality of a system making it more flexible and adaptable, i.e. in context-*aware* systems. As said in the beginning of this section, LBS is not the only type of system that can be considered to be a ubiquitous decision support system. However, for the reasons above, location-based services form the majority of the UbiDSS that exist or are discussed in the present literature.

5 RELATED RESEARCH

A significant body of literature exists on location-based services. Classical studies of potential location-based applications can be found (Dommety and Jain, 1996; Beadle et al, 1997), as well as recent discussions of business opportunities in LBSs and customer value proposition (Rao and Minakakis, 2003; Barnes, 2003). Overviews of LBS enabling technologies are present in books devoted to LBSs (Hjelm, 2002; Jagoe, 2003), and journal papers (e.g., Dao et al., 2002; D'Roza and Bilchev, 2003). Discussions of high-level architectural issues in LBSs (Jose et al., 2003; Nicklas and Mitschang, 2004), and a discussion of strategic issues related to an LBS development and service portfolio selection (Tilson et al., 2004) can be found as well.

However, we are aware of no research done on LBS dependability issues. The reason for this is probably that the scientific community has not yet been considering LBS systems to be any different, in this respect, from other computer-based systems and thus deserving devoted investigation. However, it is much more surprising that LBS dependability is not usually mentioned even as a practical concern. The only two articles, we are aware of, that did this are the very recent Kaasinen (2005) and a short editorial by Herring (2001). Articles speculatively discussing success factors of LBSs (Grajski and Kirk, 2003; Bisdikian et al., 2001; Unni and Harmon, 2003) mention several different factors, including technological maturity including positioning accuracy, privacy protection, usability of interfaces, price-value correspondence, personalization and some other. They do not, however, mention dependability as a success factor. Articles based on user interviews (Kaasinen, 2003; Köhne et al., 2003; Osman et al, 2003) manage not to overlook the content quality, the most obvious dependability concern (see Section 3). However, Kaasinen (2003) is the only article among those three that discusses, yet very briefly, content quality as a real issue for service developers/providers.

It is important to notice that LBS-related research is fragmented. Even after being a hot topic for a decade, LBSs did not institutionalize as a research field – LBS-related investigations are carried out relatively independently in various research communities. These include mobile commerce (e.g. ICMB, 2005), Geographic Information Systems (e.g. W2GIS, 2004), databases (e.g. MDM, 2004), ubiquitous computing (e.g. LoCa, 2005), and Human-Computer Interaction (WUUELBS, 2004). Each of those communities tends to consider the use of location information as an add-on feature to their basic object of investigation, i.e. a mobile commercial application, a GIS, a spatial database, etc. – the feature that would increase efficiency, enable personalization, add value, or similar. This is probably one reason why literature concentrates too much on the positive utility side of LBSs, while issues related to potential negative consequences of using them are mainly overlooked. The risk of the user's location privacy violation is probably the only such issue, the existence of which is well-understood, recognized by legislative bodies (e.g. Directive 2002/58/EC), and widely discussed in the research literature (e.g. Markkula, 2001; Minch, 2004).

A considerable body of research is available on data management in LBSs. As Lee et al. (2002) list, the range of the studied questions includes data placement (centralization vs. distribution), data replication, indexing, query scheduling, data caching, broadcast (push) strategies, and combination of broadcast with on-demand access. As can be seen, the research has been concentrating on the querying and delivering part of the activity of communication of the location-dependent data to the point of use. Mobile HCI and GIS communities did also research into methods of data representation in LBSs (Chincholle et al., 2002; Zipf, 2002). These streams of research will be overviewed and some of their findings utilized in Chapter 7.

Related research also includes studies in such fields as Data and Information Quality (Wang and Strong, 1996; Parssian et al., 1999; Motro and Rakov, 1998), Software Reliability Engineering (Musa, 1998), Software Testing (Beizer, 1990) and Requirements Engineering (Wiegers, 2003). These research fields will be reviewed in appropriate chapters of this dissertation.

6 RESEARCH APPROACH

This section presents the research approach of this dissertation, including the research framework, the research process, and research methods used.

6.1 Research Framework

The research framework applied in this dissertation was first introduced in March and Smith (1995). Its evolution has been recently presented by Hevner et al. (2004). The framework (as in Hevner et al.) is depicted in Figure 1 and described in the following paragraphs.

The *environment* defines the problem space in which the phenomena of interest reside. For IS research, it is composed of people, organizations, and their existing or planned technologies. The people's goals, tasks, problems, and opportunities, shaped by roles, characteristics and capabilities of people, assessed and evaluated within organizational context, and positioned relative to the existing technology, define the *business needs* or "problem" as perceived by the researcher. Framing research activities to address business needs assures research *relevance*.

Given a business need, IS research proceeds in two complementary activities. *Behavioral* (or *traditional*) *science* attempts to explain and give means for predicting phenomena related to the identified business need, which leads, at its best, to development and justification of *theories*. In turn, *design science* attempts to meet the business need by building and evaluating *artifacts*, which are classified into concepts, models, methods and instantiations. Behavioral science is descriptive, passive (or reactive) with respect to technology, and seeks for *truth*. Design science is prescriptive, proactive with respect to technology, and seeks for *utility*. Hevner et al. (2004), following the arguments of pragmatism, state that truth and utility are inseparable, they are the two sides of the same coin, and that scientific research should be evaluated in light of its practical implications. They put it as: "truth informs design and utility informs theory". They argue therefore that both types of science are necessary and should be engaged in a complementary research cycle. It is important to note that design science is not the same as *routine design,* which is the application of existing knowledge to some problems. In contrast, design science addresses unsolved problems in unique or innovative ways or solved problems in more effective or efficient ways, thus making some contribution to the archival knowledge base (Hevner et al., 2004). Iivari (2003) makes similar distinction but uses slightly different terms: scientific constructive research results in *meta-artifacts*, which are then routinely used for creating artifacts – information systems.

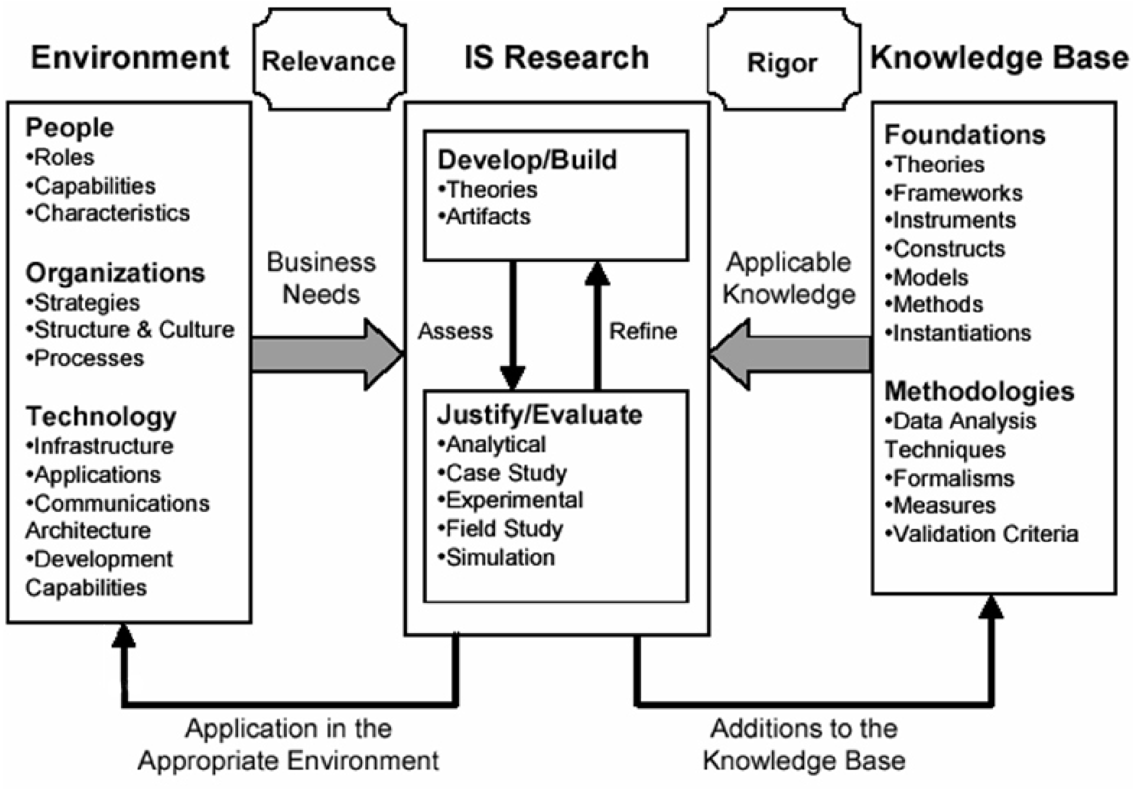

FIGURE 1 Information Systems Research Framework (Hevner et al., 2004, p.80)

On the other side of the framework, there is the *knowledge base* composed of foundation and methodologies. *Foundations* come from prior research in IS or reference disciplines, and contain theories, frameworks, instruments, methods, etc. Foundations are used in the *design/build* phase of a research study. Methodologies, in turn, provide guidelines used in the *justify/evaluate* phase. Research *rigor* is achieved by appropriately applying existing foundations and methodologies, i.e. *applicable knowledge*.

Finally, the *contributions* of a research study are assessed as they are applied to the business need in an appropriate environment and as they add to the content of the knowledge base for further research and practice.

6.2 Research Process and Methods

As in the research framework described above, the present study combined traditional-science and design-science paradigms. Given the identified business need, which is *assuring dependability of location-based services*, traditional-science research attempted to explain phenomena related to this business need, while design-science research attempted to build artifacts, mainly of the method type, to aid in meeting the business need. The two parts were not separated in time, but rather engaged in a complementary cycle with a few iterations. Findings from the traditional-science part were focusing the design efforts, while empirical experiences of building and evaluating design artifacts were forming an important part of data on which the traditional-science analysis relied.

The two major iterations of the research cycle roughly corresponded to the two industry-cooperation research projects, in which the author of this dissertation participated. Both projects were run at the Information Technology Research Institute of the University of Jyväskylä. The first project, MultiMeetMobile (2000-2002), studied m-commerce in general, and location-based services in particular, with respect to their general requirements, and existing and future technologies. The study was first *conceptual-analytical* (Järvinen, 2001); then it proceeded into the design of a pilot LBS system, i.e. research using *system development* (Nunamaker et al., 1991). The design resulted in a working prototype, referred to as Multimeetmobile Location-based System (MLS). Experiences gained during building and evaluation of MLS helped elaborate further our understanding of LBS requirements and issues. The final report of the LBS part of the MultiMeetMobile project is the article included as Chapter 2 in this dissertation. Detailed description of MLS is out of the scope of this dissertation. It can be found in Virrantaus et al. (2001) and Markkula et al. (2002). Also, already in MultiMeetMobile, a large part of the work related to the design of the method for communication of location-dependent data in LBSs (Chapter 7) was performed and the basic implementation of the method became a feature of MLS.

The second project, KOTEVA (2002-2004), studied issues related to software-based systems quality assurance. Dependability of mobile, and in particular location-based, services became a studied issue thanks to the participation of the mobile phone operator Radiolinja, now Elisa. In this iteration of the research cycle, starting with knowledge gained in MultiMeetMobile, dependability of LBSs was conceptually analyzed, and five major types of development faults possibly affecting LBS dependability were identified and analyzed (see Section 3 and Chapter 3). In parallel, a study into the software testing process improvement was accomplished in three of our industry partner companies (Chapter 9), utilizing a model-based process maturity measurement and a survey. Software as a container of faults is the most obvious of those five factors, and testing process was selected as the most beneficial issue to concentrate on.

Then, the work proceeded into design of the method for LBS data quality assessment (Chapter 4) and further elaboration of the method for location-dependent data communication, aimed for joint improvement in networking and interface quality of LBSs. Both methods were developed conceptual-analytically based on research and theoretical knowledge in adjacent fields. The method for data communication was then evaluated by experimenting with its instantiation in MLS system (Chapter 7). The method for data quality assessment was evaluated in a simulation study (Chapter 6) and during its application to a real, Radiolinja's, location-based service (Chapter 5). The latter evaluation also provided some empirical evidence for considering content quality to be an issue that needs to be explicitly addressed when developing an LBS.

In parallel with these parts of work, also a study on a system requirements quality control (Chapter 8) was performed, resulting in the development of a quality control framework. That framework can be applied, of course, when developing any kind of a computer-based system, however it is especially beneficial for innovative systems with a great variety of stakeholders such as LBSs.

Results from evaluating our design artifacts led to one more round of conceptual research, and advanced our understanding of LBS dependability issues to the level reported in this dissertation.

7 OVERVIEW OF THE INCLUDED ARTICLES

In addition to this opening chapter, the dissertation consists of eight articles. All of them have been peer-reviewed by international experts. Five articles were published in the proceedings of an international conference, and three were published in an international journal (one of them is still to appear at the time when this dissertation is written). Two of the eight articles were written by the author of this dissertation alone, the rest were written in collaboration with colleagues.

Some explaining references to the articles (dissertation chapters) were already made in Sections 3, 5, and 6. This section presents a more complete overview for each of the articles. In case of the joint papers, the overview also includes description of the author’s contribution to it.

7.1 Mobile E-Commerce and Location-Based Services: Technology and Requirements (Chapter 2)

The paper was published in Virrantaus, K. and Tveite, H. (Eds.) Proceedings of 9th Scandinavian Research Conference on Geographical Information Science (ScanGIS’03), Espoo, Finland, June 4-6, 2003, Helsinki University of Technology, 1-14.

This paper is a joint work with Aphrodite Tsalgatidou, Jari Veijalainen, Jouni Markkula, and Stathes Hadjiefthymiades. The paper is the final report of the LBS-related part of the MultiMeetMobile project and was co-authored by nearly the whole project team. The MultiMeetMobile project studied m-commerce in general, and location-based services in particular, with respect to their general requirements, and existing and future technologies. Research included both conceptual analysis and development of a pilot LBS system. This study formed the first iteration of this dissertation’s research process.

The paper reports on the knowledge collected during the project and lessons learned during design of the pilot system. It identifies and discusses basic requirements for LBSs and reports on how we attempted to meet some of them in our pilot system. The list of requirements includes requirements for functionality, usability, reliability, user privacy, location infrastructure, and service interoperability. The analysis of reliability and usability requirements formed the basis for the later work on dependability.

Because technology is an important facilitator and, at the same time, a limiting factor for LBSs, the paper also reviews the technology aspects of LBSs. This includes issues related to mobile networks, mobile terminals, and positioning technologies. In this way, the paper makes the whole of the dissertation more self-sufficient.

The author of this dissertation was one of two designers of, and experimenters with, the pilot LBS system – and the only one co-authoring this paper, since the other one left the project in 2001. As to the paper text, the section 4 on the pilot system and subsections 3.1, 3.2 and 3.3 on functional, usability and reliability requirements correspondingly are written by the dissertation's author alone. He also participated in editing the remaining three subsections of the Section 3 on LBS requirements.

7.2 Dependability of Location-Based Services: A Largely Overlooked Aspect (Chapter 3)

The paper was published in Seruca I., Filipe, J., Hammoudi, S., Cordeiro, J. (Eds.) Proceedings of 6th International Conference on Enterprise Information Systems (ICEIS'04), Porto, Portugal, April 14-17, 2004, Setúbal: INSTICC, Vol. 4, 489-496.

The paper is a conceptual-analytical study of the LBS dependability issue. The two main contributions of it is the argumentation that dependability of location-based services is a concern that deserves devoted investigation, and the analysis of major factors affecting LBS dependability.

First, the paper provides extensive argumentation in support of the claim that dependability can be a major issue affecting user acceptance of location-based services, and that many existing services seem to suffer from this problem. Also, the paper observes that LBS dependability issue is largely overlooked both in practice and research literature. It criticizes the present situation where both researchers and practitioners are too much concerned with the questions about what useful features an LBS should have, while almost completely leaving out the questions about how to assure such basic properties as reliability or response accuracy, i.e. concentrate too much on the positive utility side of LBSs, while largely overlooking issues related to potential negative consequences of using them. The paper also discusses briefly the likely reasons for such a bias in attention.

Second, the paper identifies and analyses five major types of development faults in LBSs, i.e. factors affecting LBS dependability. First, content is of paramount importance in LBSs since it is the core of the LBS service provision. Second, software is a traditional concern and source of faults in computer-based systems. Third, a gap between the user requirements and selected algorithmic or technological solutions may seriously affect the quality of decision support provided to the users. Fourth, networking restrictions, if not taken properly into account, may cause service timing failures. Fifth, interface is another traditional concern and source of faults that may affect both the effectiveness and efficiency of achieving user's intended goals. The paper discusses each of these five factors with respect to its nature and possible approaches to treating it.

7.3 Information Quality Assessment of a Yellow-Pages Location-Based Service (Chapter 4)

The paper was published in Proceedings of 27th International Computer Software and Applications Conference (COMPSAC'03), Dallas, USA, November 3-6, 2003, Los Alamitos: IEEE Computer Society, 320-326.

This paper is a joint work with Prof. Markku Sakkinen. The author of this dissertation performed the greater part of the work, related to both running the research study, design of the proposed solution, and writing the text of the paper.

The paper tackles the issue of LBS content quality. Content faults such as inaccuracies and omissions form a major factor posing threat to LBS dependability (see Section 3).

In present practice, the content is seldom created specially for a location-based service, but usually repurposed from readily-available sources such as yellow-pages directories, map databases, etc. Therefore, while being an important issue, the task of improving the quality of LBS content, if insufficient, is usually outside the scope of things under the direct control of LBS developers and providers. On the other hand, the task of evaluating the quality of the available content is very important. The results of the evaluation can then aid decision making about whether it is sensible to develop the service at all, lead to negotiation with the content provider, and facilitate the selection process (if several datasets are available). In this part of the study, we selected, therefore, this issue of assessing the fitness of the LBS content for the service task, i.e. actually the effect of the content faults on the dependability of the service.

The paper reviews research from two fields, Information Quality and Software Reliability Engineering (SRE), and makes an intermediate conclusion that neither of those provides a readily-available solution. Then, the paper develops a quality assessment method, which is a hybrid of approaches from those two fields. In fact, the contribution of our work may be seen as twofold: we applied SRE methodology for assessing the content quality of an LBS, and based on the knowledge from the information quality field developed a modification of SRE, 2-Branch.

SRE coupled with 2-Branch measures the data quality in the form of a statistical probability of getting the correct answer to a user query, i.e. reliability (see Section 2). However, only the effect of data faults is measured, while the effects of software or algorithmic faults are effectively separated. 2-Branch also facilitates the problem of verifying the conformance of query results to the real world, i.e. the oracle problem, which is identified as the most difficult and expensive issue. The main distinctive feature of 2-Branch is that the assessment proceeds by two branches, which are then statistically combined.

In the paper, a location-based service, which serves “find N nearest restaurants” type of queries, is considered. However, the general approach is applicable to a broad range of services.

7.4 Content Quality in Location-Based Services: A Case Study (Chapter 5)

The paper was published in Proceedings of International Conference on Pervasive Services (ICPS’05), Santorini, Greece, July 11-14 2005, Los Alamitos: IEEE Computer Society, 461-464.

This paper is a continuation of the COMPSAC’03 article (section 7.3), and is a joint work with Prof. Markku Sakkinen as well. Division of the work was similar to that in the case of the COMPSAC03 article. Also, all the field and programming work was done by the author of this dissertation.

This paper reports on how we applied our content quality assessment method to the Radiolinja’s LBS service (referred to, by us, as MFS), which was under development at that time. This study could be interpreted as both a field experiment for evaluating the feasibility and effectiveness of the method itself, and as a case study of that LBS. The paper describes the context of the study, then briefly presents the evaluation method, and then explains how it was implemented in the case of MFS, thus providing for better understanding of the method and demonstrating that it is relatively cheap to use.

Our evaluation has shown that the reliability of the MFS service at its initial stage, due to the content faults alone, was well below the level one could consider sufficient. Most LBS research studies share a common assumption that, somewhere out there, there exists some content in which a mobile user is interested and even willing to pay for. This study provided, however, some empirical evidence for that the LBS content quality is an issue to be explicitly addressed in both practice and research, and for the need of making such content quality measurements. The paper presents discussion of these findings. It includes also some analysis of reasons behind such an insufficient data quality level, which is mainly related to direct reuse of data not created with LBS-specific requirements in mind, in this case data from a phone book.

7.5 Content Quality Assessment and Acceptance Testing in Location-Based Services (Chapter 6)

The paper is to appear in International Journal of Pervasive Computing and Communications (JPCC) 2(3) (Troubador Publishing Ltd, UK, 2006).

This paper belongs to the same line of research as the two articles above. It is a joint work with Prof. Jari Veijalainen and Prof. Markku Sakkinen. The main additional contribution of the paper is that it reports on a series of simulation experiments aimed at evaluating our approach to assessing the content quality in a location-based service (section 7.3). The work on this additional contribution was performed by the author of dissertation alone. This article also elaborates deeper than the previous works on some details and underlying assumptions of the 2-Branch method. This is a joint contribution of all the three co-authors.

In the experimental study, first, our modification of the Software Reliability Engineering (SRE) methodology, 2-Branch, is compared to the standard SRE. The experiments indicate that 2-Branch has in most cases a lower measurement error than the standard SRE. A corollary to that is that 2-Branch can achieve therefore as low an error level as the standard SRE, but using a worse oracle. Getting a good oracle is probably the main cost factor in testing an information service, being able to use a cheaper one may therefore result in significant savings. Using positioning errors as an example, another important feature of 2-Branch is demonstrated: the ability of separating data flaws from any other factors that may cause contextual failures. The black-box nature of the standard SRE does not allow this.

Next, this paper experimentally analyzes some properties of SRE methodology as such in the context of an LBS. In particular, several types of measurement errors are analyzed. E_Q is an error coming from the finiteness of the number of sample test inputs. E_C is an error created by using an alternative source of information, instead of "the real state of the world" to which one usually does not have access (2-Branch reduces this error). E_{ID} is an error created by imperfection of the expected input distribution. E_Q is the only type of error that is accounted for in SRE mathematics. The paper discusses how the presence of other errors affects the total measurement error, and how it affects the decision risks in a situation where the quality measurement is used as a basis for making an accept/reject decision.

7.6 User-Centric Data Querying for Location-Based Services (Chapter 7)

The paper was published in the special issue on Mobile Databases of International Journal of Computer Systems Science & Engineering (IJCSSE) 20(2), 95-103 (CRL Publishing Ltd, UK, 2005).

This paper tackles the activity of communication of location-dependent data to the LBS users. Unlike most studies, this paper treats communication as an indivisible issue and develops a core holistic approach. The developed method aims for joint improvement of interface usability and networking quality, which are two of the five major factors affecting LBS dependability (see Section 3).

The paper reviews research in the location-dependent data management field and LBS-related research in HCI and GIS fields. It observes that those two streams of research proceed quite independently, concentrating on technical and cognitive aspects correspondingly, even while those are ultimately interrelated.

The paper then develops an integrated solution, which is based on a novel type of LBS queries, which we consider to be appropriate for implementing "neighborhood description", "route presentation", and similar functions in location-based services. First, those queries are not only location-dependent but also context (and preferences) dependent, i.e. spatio-contextual. Second, they are also focused, meaning that some objects or areas, e.g. those that are closer to the current user location, are represented with more detail than other. And third, those queries are motion-adaptive.

The attempt is to make the system as user-centric as possible and in this way to maximize the usability of the service under restrictions on data volume that can be transmitted over the network and presented to the user, imposed by technical, economical and cognitive factors of mobile environments.

The paper develops a computational model for handling such queries. Finally, the model is instantiated and implemented for a simple LBS, and the results are presented and discussed.

7.7 Requirements Quality Control: A Unifying Framework (Chapter 8)

The paper was published in Requirements Engineering journal 11(1), 42-57 (Springer-Verlag London, UK, 2006).

This paper is a joint work with Prof. Markku Sakkinen. The author of this dissertation performed the greater part of the work.

This paper is a study on the quality control of software and system requirements. Roughly speaking, controlling quality of requirements refers to checking whether the requirements as developed and stated are correct and should be implemented.

Literature tends to discuss software (and system) requirements quality control as a heterogeneous process based on application of a great variety of relatively independent techniques. Books present some sets of "good practices" for that, journal and conference articles as a rule discuss one of those good practices in detail. The present paper develops a unifying framework for requirements quality control. It provides a more coherent view on this important activity, and aims for increasing the effectiveness and efficiency of the process. The framework consists of the two basic activities, review and translation, and the four pools: stakeholders, requirements quality criteria, review reading techniques, and requirements representation forms.

This framework can be applied, of course, when developing any kind of computer-based system, however, it is especially beneficial for innovative systems with a great variety of different stakeholders such as location-based services.

While the ScanGIS'03 article (Section 7.1) discussed general LBS requirements, which hold true for all or at least most of location-based services, the present paper provides a tool to be used when developing requirements for a specific service. As discussed in Section 3, a type of development fault posing threat to LBS dependability is when an algorithm implemented into a particular service is inappropriate, e.g. too imprecise, for the service purpose. Such faults are in fact requirements faults, they get introduced into a system as a rule because the requirements, on which the system design is based, are either incomplete of inaccurate. Assuring and controlling the quality of stated requirements during the early stages of the development process is, therefore, the main tool for reducing the probability of introducing such faults.

7.8 Insufficient Education Hinders Good Testing – A Case Study (Chapter 9)

The paper was published in Sahni, S. (Ed.) Proceedings of the IASTED Computer Science and Technology Conference (CST'03), Cancun, Mexico, May 19-21, 2003, Anaheim: ACTA Press, 32-37.

This paper is a joint work with Jarmo Ahonen, Tuukka Junttila and Markku Sakkinen, i.e. it is co-authored by the whole team of the KOTEVA project. The author of this dissertation participated both in the analysis of the collected data, and in writing the paper.

The paper is a report on our study into the software testing process improvement, which was accomplished in three of the KOTEVA industry-partner companies. One of those is Radiolinja (that has own design and development units). The two others are software development companies that are among the leaders on the Finnish market and extensively involved in development of mobile services and applications. All three, therefore, either have already been or will likely be yet engaged in development of LBSs. As discussed in Section 3, the quality of software, both on the server and on the client side, is a major factor affecting LBS dependability. The software used in an LBS system should therefore be subjected to rigorous testing. For these two reasons, the findings reported in the present article are relevant to the development of LBSs.

The quality of software is a quite elaborated research area. The studied tools include programming schemes and software development methodologies – for reducing the probability of introducing a fault, and various testing techniques – for finding and removing the faults that might nevertheless be introduced. One sub-area that is less elaborated is the testing process itself, and in practice testing is often done in an ad-hoc way. Testing process was selected therefore as the most beneficial issue to concentrate on in this part of the study.

Our basic assumption before doing practical analysis of the testing processes of the participating companies was that their software processes would not include adequate quality assurance, and therefore should be improved. A Test Improvement Model (TAM) based process maturity measurement showed, however, that this was not completely true. The most surprising aspect of those problems was that although there were proper phases in the testing processes of the companies the outcomes of those phases were not very good.

Then, a small survey among the employees of the companies, who deal with testing in their work, was accomplished. The aim of the survey was to find out the availability of skills required for proper testing. However, we did not ask the people directly about their skills (objective self-assessment is difficult), but about the education and training they had got. This result showed that the average level of training received was very small.

The study reported in this paper indicates that the normal process-improvement thinking alone does not enable sufficient improvements in the quality of testing and the quality of the final software. Somewhat surprisingly, the study concluded that the most beneficial area to concentrate on for increasing the quality of software in practice is providing enough quality-related training to personnel, rather than the process improvement as such.

8 CONCLUSIONS

This section discusses the contributions of this dissertation and presents some of possible future work directions.

8.1 Contributions

According to Hevner et al. (2004) (see Section 6.1), the contributions of a research study are formed by two constituents. First, the results of the study must be applicable to a business need in an appropriate environment, i.e. aid in solving relevant practical problems. Second, in addition to that, the study should make some contribution to the archival knowledge base for further research and practice.

The relevance of this dissertation is created by the fact that the research activities were framed to address the problem of assuring dependability of location-based services. As argued in Section 3 and throughout the dissertation, requirements for dependability are high in LBSs. Therefore, assuring dependability is not straightforward, and dependability can be a major issue affecting user acceptance. Therefore, without resolving this problem, the great LBS business potential is unlikely to be seen fulfilled. The present study and its findings hopefully prove important to all the parties in the LBS business, including mobile operators, content providers, and others. With this in mind, all the articles included into the dissertation are written in a practice-oriented yet scientific way, and with a goal to present research effectively both to technology-oriented and management-oriented audiences.

With respect to this business need, the dissertation contributes by developing solutions to several problems that were identified as being of the most benefit for LBS dependability. The first is the method for assessment of the data quality in an LBS, the second is the method for communication of location-dependent data to the users, aiming for joint improvement of interface usability and networking quality, and the third is the framework for the quality control of the system requirements. Also, the testing process improvement study resulted in some practically relevant findings.

In addition, the dissertation contributes to the knowledge base by advancing our understanding about what location-based services are and what requirements to them are. In particular, the dissertation analyzed general LBS requirements, requirements for dependability, and major sources of faults posing threats to LBS dependability. The results of these analyses are of relevance for further research and practice. Also, since the dependability aspect of location-based services seems to be largely overlooked among both LBS researchers and practitioners, the dissertation makes an additional contribution by arguing and providing some empirical evidence from the pilot studies for the importance of taking the issue seriously into account. Finally, the developed methods also present contribution to knowledge, since they are themselves knowledge of "how to" type, and may become a basis for future research.

8.2 Further Research

Some issues for future research related to the developed methods can be found in the corresponding sections of the corresponding chapters. Let us discuss here some more general future work directions.

Our work on LBS data quality assurance provided a solution for measuring that quality. Our method is relatively cheap to apply and, therefore, can be continuously used to monitor the quality of content in a service and in that way to realize when improvements are needed. However, this does not solve the problem of how to improve the content quality if insufficient for the purpose. Since many LBSs have to use content repurposed from other sources, this is really an acute problem, yet it is too much a business issue to be within the scope of this dissertation.

Regarding software quality, we concentrated on testing process improvement rather than on some special testing techniques. It is, in part, because the basic techniques for software testing and quality assurance apply to any kind of software-based systems including LBSs. However, web and mobile technologies already require new testing and bug analysis methods (Nguyen et al., 2003), making it worth writing special books on testing internet-based and mobile systems. Probably, the LBS context also requires development of new or adaptation of existing methods.

Regarding requirements-algorithm misfits, an important issue is how to balance utility of the service with dependability achievable due to technical and other restrictions. The article of Tilson et al. (2004), discussing the process of selection of the LBS strategy and the service portfolio in presence of technical restrictions and uncertainties, is relevant to this question. It does not address dependability; however, it may be used as a basis for study.

The following list summarizes the above mentioned issues for future work, and extends them with a few other important conceptual and business-oriented questions:

- How to achieve sufficient dependability of LBSs with repurposed content?
- Whether LBSs require development of new, or modification of existing, testing and fault analysis methods? Of what kind?
- How to balance utility of the service with dependability achievable due to technical and other restrictions?
- What are potential consequences of LBS flaws?
- How dependability influences LBS adoption?
- Since dependability may be an asset that is difficult to duplicate, could this be a competitive advantage? How should the marketing of dependable LBSs be conducted?
- With what investment an acceptable level of LBS dependability can be achieved?
- What players in the LBS value chain/network should be responsible for dependability?

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YHTEENVETO (FINNISH SUMMARY)

Mobiiliverkkokaupalle on ennustettu suurta tulevaisuutta, ja siitä on arvioitu tulevan merkittävä tekijä liiketoiminnassa ja yhteiskunnassa. Paikkaperusteiset palvelut puolestaan mainitaan usein yhtenä mobiiliverkkokaupan lupaavimpana alueena. Paikkaperusteinen palvelu on "käyttäjän antamaa tai paikannuslaitteen tai paikannettavan laitteen avulla saatua sijaintitietoa hyödyntävä lisäarvopalvelu" (Tekniikan Sanastokeskus, 2002). Sellaisesta palvelusta voi saada tiedon esimerkiksi siitä, missä matkaviestimen käyttäjä hakuhetkellä on, sekä lisäksi tietoa erilaisista palveluista, kuten lähimmästä ravintolasta, hotellista tai huoltamosta ja niiden sijainnista.

Vaikka paikkaperusteisten palvelujen markkinapotentiaali on suuri, niissä on vielä ylitettävä useita huomattavia esteitä, joihin kuuluvat päätelaitteiden automaattisen paikannuksen tekniikkojen epätäydellisyys ja kustannukset, yksityisyysongelmat ja standardien puute.

Tämä tutkielma käsittelee paikkaperusteisten palvelujen luotettavuutta – seikkaa, jonka uskomme olevan yksi niiden kriittinen menestystekijä ja joka näyttää olevan tällä hetkellä lisäeste niiden liiketoimintamahdollisuuksien toteutumiselle. Järjestelmän luotettavuus tarkoittaa sen kykyä tarjota sellaista palvelua, johon sen käyttäjät voivat perustellusti luottaa. Tutkielmassa käsitellään useita luotettavuuden päänäkökohtia, kuten paikkaperusteisten palvelujen sisällön laatua, ohjelmiston luotettavuutta, käytettyjen algoritmien (mm. paikannusmenetelmän) soveltuvuutta, verkkotoiminnan laatua (ts. verkon rajoitteiden huomioonottamista) ja käyttöliittymän laatua.

Tutkielman kontribuutioihin kuuluu paikkaperusteisten palvelujen luotettavuuden käsitteellinen analyysi sekä ratkaisuja muutamiin ongelmiin, jotka havaittiin hyvin tärkeiksi luotettavuudelle. Ensimmäinen näistä ratkaisuista on palvelun sisällön laadun arviointimenetelmä, toinen on paikasta riippuvan tiedon käyttäjille välittämisen menetelmä, jolla pyritään parantamaan sekä käyttöliittymän että verkkotoiminnan laatua, ja kolmas on järjestelmävaatimusten laadunvalvonnan kehikko. Lisäksi työssä on kehitetty käytännöllisiä suosituksia testausprosessin parantamiseksi.

Pääosa tutkielmasta on tehty tutkimushankkeessa, jossa oli mukana yritysosapuolia, ja siinä keskityttiin sellaisiin ongelmiin, joita tiedeyhteisö ei ollut ratkaissut, mutta joihin nämä yritykset törmäävät jokapäiväisessä toiminnassaan. Toivomme, että tämä tutkielma ja sen havainnot ovat hyödyllisiä kaikille paikkaperusteisten palvelujen liiketoiminnan osapuolille: verkko-operaattoreille, sisällöntuottajille, ohjelmistoyrityksille ja muille.